Sewage Works Journal

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Sewage Works

DEVELOPMENTS IN SEWAGE DISPOSAL FOR SAN FRANCISCO *

By Clyde C. Kennedy

Consulting Engineer, San Francisco, Calif.

At the present time the City and County of San Francisco is proceeding with a program of sewage treatment and disposal which will entirely eliminate the discharge of untreated sewage and objectionable industrial waste into the adjacent shore waters except during periods of heavy storm water runoff. This program was outlined in a report entitled "The Treatment and Disposal of the Sewage of the City and County of San Francisco, California" which was submitted to Mr. W. H. Worden, Director, Department of Public Works, by a Board of Consulting Sanitary Engineers composed of Harrison P. Eddy, Charles Gilman Hyde, Leon B. Reynolds and the writer in May, 1935.

The condition which brought about the engineering study was the gross pollution of Bakers Beach and the Marina recreational park on the north shore line of the city, which are protected from wind and used by the public during the greater portion of the year. Prior studies made by the Department of Public Health had revealed that the shore waters were more or less polluted with sewage for the entire length of the shore line. The length of this shore line bordering San Francisco Bay on the east, Golden Gate Strait on the north and the Pacific Ocean on the west is 23 miles.

The general conditions were recognized by the Department of Public Works and the instructions in the agreement of the Consulting Board provided that it should—"inspect all local conditions affecting the problem, —advise as to the proper location of plants and outfalls" and—"recommend type of process that should be adopted—." In the plant construction already undertaken and in the plant design under way, recommendations of the Consulting Board have been followed as to general plant location. The developments in sewage treatment processes and the upgrading in the requirements of the State Department of Public Health since the report was prepared, have resulted in a change in the type and the degree of treatment which is provided for in the carrying out of the program.

Geographical Conditions

San Francisco occupies the northerly portion of the peninsula which terminates in the Golden Gate. A spur of the Coast Range forms a central ridge which roughly divides the city, one-third on the western or Pacific Ocean slope and two-thirds on the eastern or San Francisco Bay slope. A low ridge forms a T with the main spur and extends from Telegraph Hill on the San Francisco Bay shore to the Cliff House on the ocean. The area to the north of this ridge is cut into a considerable number of drainage areas tributary to the north shore. The highest point in the main spur is at practically the geographical center. Here are Twin Peaks, which rise to an

* Presented at Twentieth Annual Meeting, Federation of Sewage Works Associations; San Francisco, Calif.; July 21–24, 1947.

elevation a little more than 900 feet. Numerous spurs from the central backbone extend to the east and to a lesser degree toward the west, and divide the city into well defined drainage areas which open out upon the bay or ocean.

The total land area of San Francisco is 30,700 acres or 48 sq. mi., including some presently submerged areas in the southeast portion of the city which will probably be reclaimed to the projected bulkhead line. Included in the total area are 3,250 acres devoted to municipal parks and playgrounds and more than 2,000 acres in military and naval reservations.

Politically the area has a combined city and county government. The boundaries are fixed by the line of San Mateo County on the south and by the adjacent waters separating it from Alameda and Marin Counties on the east and north. Efforts to extend the boundaries southerly have been unsuccessful. Due in part to these political barriers and in part to the pattern of residence development on very narrow lots, the population density on built-up areas has been comparatively high. For the most part, residential development of homes on larger lots has been and will probably continue to be in the cities to the south and across the bay to the east and north.

Population

The present population of San Francisco is estimated at 900,000. This population is remarkably close to that forecast by C. E. Grunsky nearly 50 years ago. On this basis, the population forecast for 1960 is 1,100,000, approximately 44 persons on each acre, which is nearly maximum for the area unless an entirely new type of development should take place. In character the city is largely residential and commercial. While there are many industrial and manufacturing plants in the city, there are none which contribute great quantities of industrial waste. The sewage is typical strong domestic, relatively high in grease content. The strength measured in suspended solids varies in the different districts from slightly under 300 p.p.m. to more than 400 p.p.m.

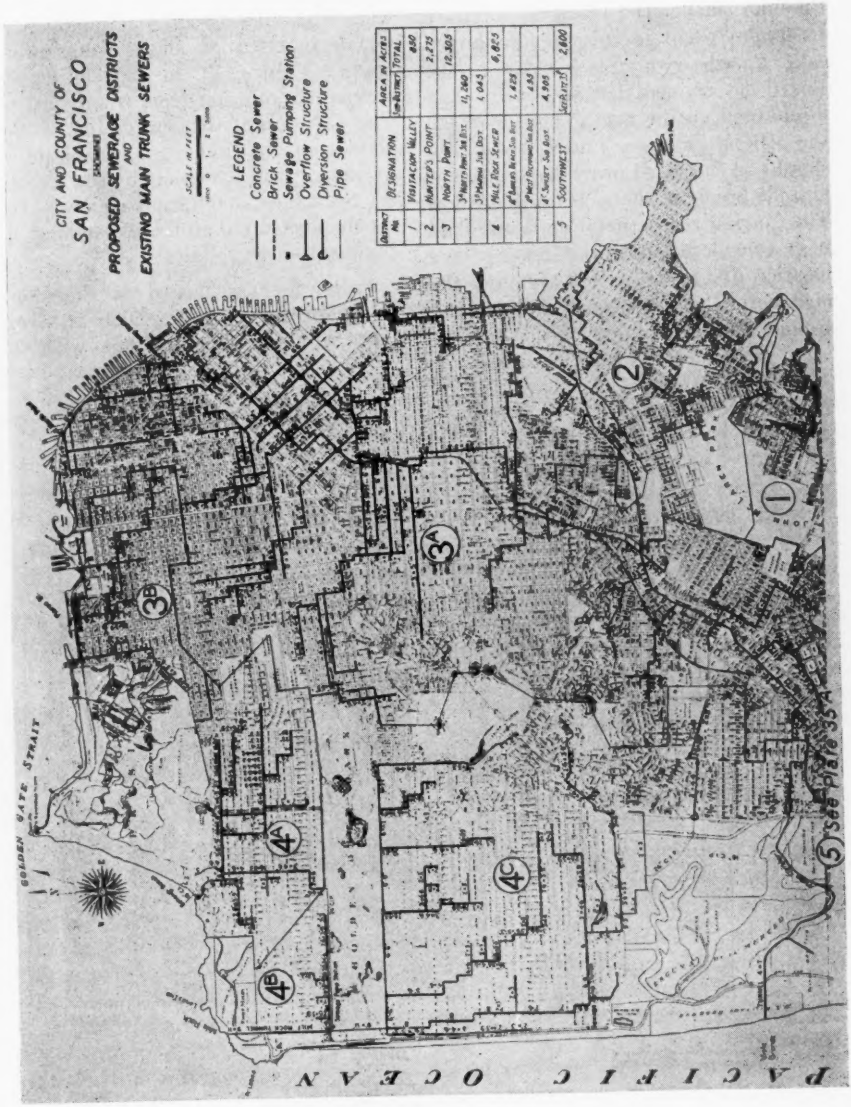
Sewer System

The general system of sewers was laid out at the beginning of the present century under the direction of Mr. Grunsky. For the most part it is a combined system. The type was determined in part by the sewers already built and in part by the then current practice of carrying untreated sewage into coastal waters by means of long outfalls. It provided for concentration of the flow at points deemed most suitable for the construction of outfall lines. The location of these outfalls determined the sewerage districts for which disposal was recommended by the Consulting Board.

The trunk lines which had been constructed under the plan developed by Mr. Grunsky were the Mile Rock sewer discharging on the North Shore a short distance east of Point Lobos, the Bakers Beach sewer, the Pierce Street sewer and the North Point sewer. In addition the areas tributary to Islais Creek, termed in the report of the Consulting Board, the Southeast district, the Visitation Valley district and the Southwest district were included in the study.

Investigations by Consulting Board

The record of performance with short outfalls laid in excavated trenches at Bakers Beach and Pierce Street demonstrated that the tidal currents in Golden Gate Strait were destructive to such structures, since both were broken after only a short period of service. Investigation of the scouring action in this channel led to the conclusion that in the main Golden Gate Strait channel very great construction difficulties would be encountered in any long outfall line. Based on this conclusion it was determined


CITY AND COUNTY OF
SAN FRANCISCO
CALIFORNIA
PROPOSED SEWERAGE DISTRICTS
AND
EXISTING MAIN TRUNK SEWERS
SCALE IN FEET
LEGEND
Concrete Sewer
Brick Sewer
Sewage Pumping Station
Overflow Structure
Diversion Structure
Pipe Sewer
DISTRICT No.
DESIGNATION
AREA IN ACRES
WATER
TOTAL
1 VISITACION VALLEY 650
2 HUNTERS POINT 2,275
3 NORTH POINT 12,305
3A North Point Sub Dist. 11,260
3B Marina Sub Dist. 1,045
4 MILE ROCK SEWER 6,815
4A Islais Creek Sub Dist. 1,435
4B Point Lobos Sub Dist. 1,135
4C Lake Sub Dist. 4,245
5 SOUTHWEST 2,800
See Plate 35-A
GOLDEN GATE STRAIT
PACIFIC OCEAN

to reduce the number of outfalls to the least practicable number.

Unfavorable foundation conditions along the north shore west of the Presidio made the location of any treatment plant in this area impractical. Faced with this condition the Board determined that all sewage then discharged on the north shore between the Mile Rock sewer and Lobos Creek should be conveyed away for treatment and disposal at more favorable sites. The Marina recreational area was likewise considered unsuited for a plant location due to its limited area and the obstruction of the park area facing Golden Gate Strait.

Float studies were made at various points along the shore with several types of floats. The movements of sewage fields were observed from shore with dyes added to the sewage. Bacterial analyses of shore water were made (Figure 1) to determine the spread of pollution from sewer outlets. The diffusion of the sewage in the Bay waters after discharge were studied by noting the variation in the electrical resistance at different depths. The conclusions based on these tests may be summarized as follows:

1. Sewage discharged at the shore or at distances up to 2,000 ft. from shore would not readily mix with the

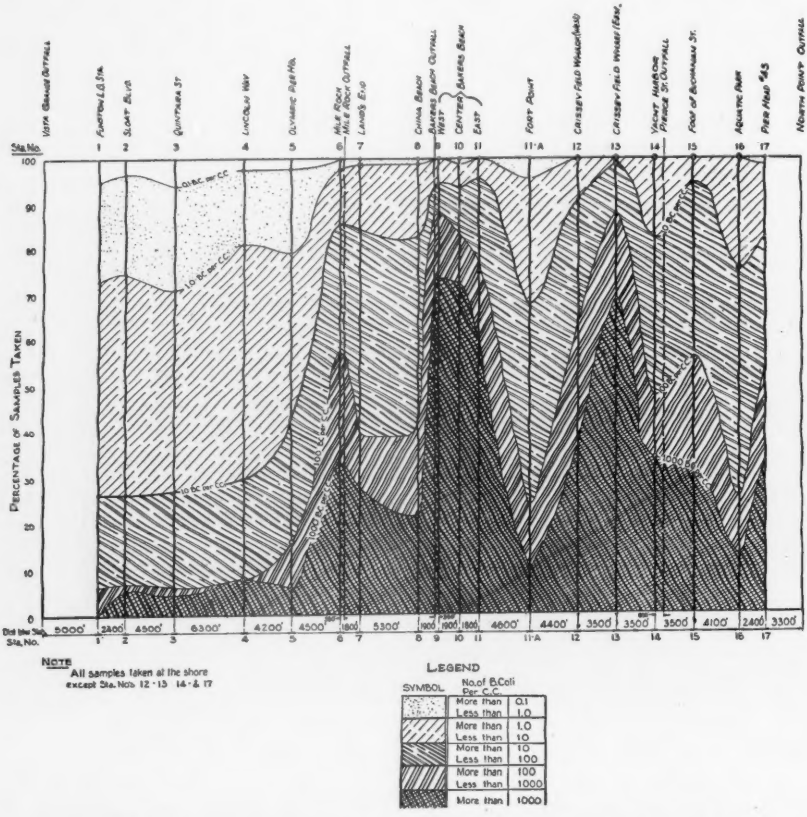


FIGURE 1.—Average numbers of *B. coli* in shore waters at San Francisco; February 6, 1933 to February 7, 1934.

main tidal currents in Golden Gate Strait but would be carried shoreward and along shore, moving back and forth with the tide for considerable periods of time, sometimes several days.

2. Sewage rose to the surface as an unbroken mass in a very short time and spread in a thin film over a gradually widening area, then moved shoreward or along shore as indicated by the sewage fields clearly outlined by the addition of dye to the sewage flow and by the spread of "slick" fields. The thin layer of grease-coated and gas-buoyed sewage particles polluted the waters along the entire shore line in varying degrees along the bay and ocean frontage.

Recommendations of Consulting Board

Based on the results of the investigations carried out under the direction of the Consulting Board, the program of construction summarized below was recommended:

1. That the sewage of the Bakers Beach area should be diverted and carried by a tunnel and trunk sewer to a treatment plant location in Golden Gate Park adjacent to the Mile Rock sewer, and that by suitable diversion and pumping the sewage flow from the Bakers Beach, Richmond, West Richmond and Sunset districts should be treated in a single plant. Such plant would provide for grease and scum removal, removal of settleable solids by sedimentation, with digestion of grease and organic solids in heated sludge digestion tanks, sludge filtration and discharge of the effluent into the Mile Rock sewer. It was recommended that the effluent be disinfected by chlorination during the bathing season unless or until an underwater outfall should be determined as practical to carry the effluent far enough out into the Golden Gate channel to prevent return to shore.

2. That the sewage from the Marina district should be diverted by pumping through a pressure and gravity line to a connection with the existing North Point sewer, with the understanding that this sewage would be treated with the sewage from the North Point district at a plant near North Point.

3. That the sewage from the area tributary to North Point together with a portion of the sewage from the Southeast district should be treated near North Point by grease and grit removal and by screening through fine screens with disposal through an outfall more than 2,000 ft. long in water 50 ft. deep.

4. That the sewage from the Southeast district, including Visitation Valley, not carried to North Point, should be treated at a plant or plants in the general area near China Point and Hunters Point. No specific recommendations for treatment were set up in the report for the Southeast district.

5. That the sewage from the Southwest district which, geographically, included an area in San Mateo County, either should be given complete treatment before discharge into the ocean or pumped through a pressure line to a connection with the sewer leading to the treatment plant in Golden Gate Park.

Original Construction Program—Richmond-Sunset Plant

Prior to the appointment of the Consulting Board a bond issue had been approved by the voters which, with a PWA grant, was designed to correct the existing conditions at Bakers Beach and the Marina. The first construction under the general recommendations summarized herein was limited to these objectives.

As the only practical alternative to a plant along the shore between Lobos Creek and Mile Rock, a diverting tunnel was provided to carry the sewage from the Bakers Beach sewer to a location in Golden Gate Park. The location was the subject of consider-

able negotiation with the Park Commission. A plant of the activated sludge type had previously been built in the park by the Park Commission to provide 600,000 g.p.d. of water for use in the park. The value of the reclaimed sewage and the sludge had been demonstrated to the park authorities, in particular to Mr. John McLaren, the creator of Golden Gate Park. The conditions imposed by the Park Commission were that the plant units should be fully housed or covered, should be operated without any unsightly or malodorous conditions, that the Park Commission should have all the sludge delivered as filter cake and, upon demand should be furnished up to 3 m.g.d. of plant effluent, treated to activated sludge standards, delivered to a lake in the park, to be used for irrigation and other similar use.

In 1935 design work was begun on the plant to be constructed in Golden Gate Park, which was officially designated as the Richmond-Sunset Plant, and the plant was put in operation in 1939. Concurrently the tunnel from 24th and Lake Streets to Fulton Street and the sewer line thence to the treatment plant site were designed and put under construction. The initial design requirements set up in the Consulting Board report were for a population of 200,000 with an average daily flow of 15 m.g. After the contracts were awarded for the necessary works to divert the sewage from the Marina and Bakers Beach, the funds available from the original bond issue and PWA grant were insufficient to construct the plant to the initial recommended capacity. The plant as designed and constructed was reduced to meet the requirements to the extent that available funds permitted, with provision for additional units when the increase in sewage flow required expansion.

In accordance with the original recommendations the plant provides mechanically cleaned bar rack screens, grease removal by short period aeration, sedimentation with discharge of the effluent after chlorination through the existing Mile Rock sewer, adjacent to the plant, to the waters of the Golden Gate Strait, sludge digestion, sludge filtration with provisions for storing the filter cake in bins for delivery to trucks which haul it to park storage. In working out the design, certain features then somewhat unique were incorporated; these were mechanical preflocculation to increase removal in the sedimentation process, water jet skimming, using plant effluent as the water supply, and sludge elutriation to reduce chemical cost. These features have been invaluable aids in securing adequate treatment under the existing conditions of plant overload.

Enlargement of Richmond-Sunset Plant

As a part of the present program of construction (Figure 2), the capacity of the plant is being increased by the provision of additional units to meet fully the requirements to the year 1970 or beyond. Accurate measurements of sewage flow during the period the plant has been in operation, together with records of plant performance, have furnished the basic information for the design of the new plant units. The entrance channel bar rack screens and grit-grease removal units are of sufficient capacity to take the full design flow. Two new mixing (mechanical flocculation) tanks and two new sedimentation tanks are being constructed of the same dimensions as the original units. With the new units added, the plant will provide 5 min. preaeration for grease flotation, 23 min. mixing period in the mechanical flocculation tanks and 1.08 hr. detention period in the sedimentation tanks for a flow rate of 20 m.g.d. The new construction will provide a safe margin of excess capacity when the population reaches 300,000, which is that estimated for 1970.

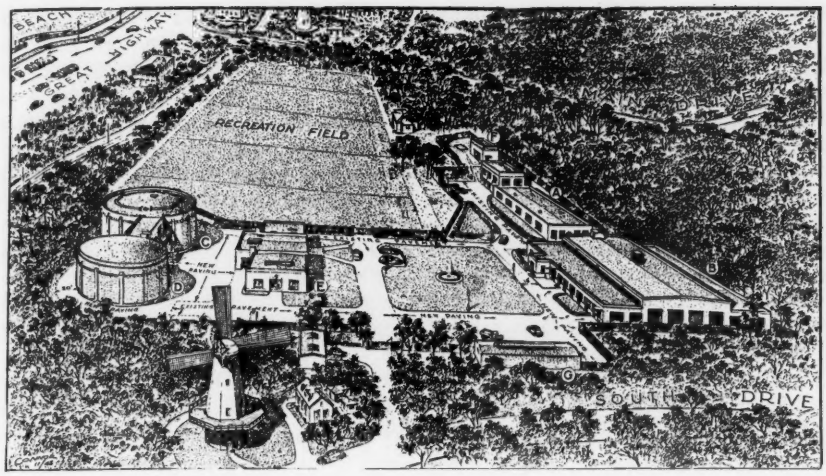


FIGURE 2.—Richmond-Sunset sewage treatment plant, San Francisco, Calif., as enlarged: A—Pretreatment Building; B—Mixing and Sedimentation Building; C—Primary Digester; D—Secondary Digester; E—Main Building; F—Non-potable Water Storage Building; G—Garage.

For reasons of economy the original housing of the sedimentation tanks was light timber construction. In the present construction the temporary timber structure is being replaced by a building of reinforced concrete with liberal use of structural glass block. In the new building, which houses both the present and the new tanks, provision has been made for adequate mechanical ventilation in the operating space to eliminate any dead air in the building.

The water spray skimming in the original construction has proven so satisfactory that the new tanks are equipped with the same type. This consists of cross lines of pipes at 15-ft. 9-in. intervals with nozzles at 3-ft. 3-in. intervals. These cross pipes are 1 ft. above the water level in the tanks and may be rotated manually to secure the most effective skimming action. All the cross pipes are connected to a header along the side of the tank. The scum material is recovered from one corner of the inlet end of the tank by means of a scum trough which is lowered by means of a cable and winch, operated manually to receive the scum while it is forced into the tank area adjacent to the trough.

The mixing or flocculation units are each 33.5 ft. square and 10 ft. deep. Each is equipped with two horizontal paddles separated by a wood baffle to maintain under flow across the tank.

The sedimentation tanks are each 100 ft. long by 33.5 ft. wide and 10 ft. deep equipped with two sprocket and chain driven flights of wood scrapers for sludge removal. The sludge is all carried to the inlet end where it is concentrated in a sludge hopper by a short cross flight scraper.

The sludge is removed from the sludge hopper by pumping from a sump below the floor of the tanks to sludge thickening tanks into which the scum is also discharged. In these tanks sludge stratification takes place. The heavy sludge sinks to the bottom, the scum rises to the top with a comparatively clear intermediate zone. In operation the top and bottom layers are pumped to the digestion tank. The middle portion is returned to the sewage inflow. Provision has been

made for enlargement of the sludge thickening tanks to meet the design flow conditions.

Four effluent launders parallel to the longitudinal axis of the tanks in addition to the end weir in each tank provide a weir with a total crest length slightly more than 900 ft. and a discharge rate of 22,000 g.p.d. per lineal foot of weir crest for the average rate of design flow.

The sludge and scum are discharged at present into an 80-ft. diameter by 32-ft. sidewall digestion tank with internal heating by four sets of vertical hot water coils. This tank has insufficient capacity to provide proper sludge digestion. Moreover, the motor driven mixing propellers so greatly interfere with the settlement of sludge that no appreciable thickening occurs. On the contrary, due to the liquefication and gasification taking place in the tank, the contents have a moisture content higher than the freshly introduced sludge and are practically homogeneous from top to bottom. The present construction provides a new digestion tank 100 ft. in diameter with 34-ft. sidewall, in which the sludge will be internally heated by a battery of ten sets of vertical hot water coils with a new type of motor-driven mixing propeller. The existing digestion tank will be remodeled as a secondary unit without heating or circulation equipment and with a gas-holder cover. With the additional digestion tank capacity, the design provides 0.95 cu. ft. per capita (300,000 population) in the primary tank and 0.50 cu. ft. per capita in the secondary tank, equivalent to 60 days holding period.

Counter current elutriation of digested sludge was provided in the original installation. The installation is of sufficient capacity to meet the expanded design requirements. In the piping rearrangement, provision has been made for the use of single stage elutriation of the primary sludge before its introduction into the secondary tank. This operation will be carried out at night. It is expected that by this operation a higher quality of digestion tank supernatant will be produced than is possible with standard practice of stage digestion operation. The provision is somewhat experimental and will be used as a guide for future design.

The elutriated sludge is conditioned by dosage with ferric chloride prior to filtration. Due to the inadequate digestion capacity, the entire contents of the digestion tank are filtered. Even with this handicap, elutriation has made possible a moderate chemical dosage. With the additional digestion tank capacity and opportunity for establishing quiescent conditions in the secondary tank, and with the aid of intermediate elutriation, a very considerable decrease in chemical requirements should be effected and a reasonably well clarified digestion tank effluent should be secured.

The elutriated sludge is at present filtered on an 8- by 8-ft. vacuum filter. An additional filter is being installed to provide a spare unit and additional capacity as and when required by the increase in sewage flow. A new flash type mixing unit will replace the present conditioning tank to eliminate the breaking of the chemical floc.

The filter cake is carried by belt conveyor to elevated hopper bottom bins from which it is loaded into trucks. This arrangement has proven satisfactory. A truck scale is being installed so that the filter cake will be weighed as handled from the plant.

The filter cake has been used in the parks and on the golf courses for the past eight years. While its value as a soil conditioner has been recognized, it has not been entirely satisfactory due to the difficulty of proper distribution. The present high cost for the park labor has greatly increased the cost of spreading and working into the ground. This difficulty has brought about a change in the manner of hand-

ling the cake. In the design of the North Point sludge treatment works at Islais Creek, provision is being made to receive the sludge cake, delivered by truck, and dehydrate it along with the sludge cake produced at the Islais Creek Plant. After dehydration it can be delivered to the park authorities in bulk and distributed without difficulty.

Provision has been made for chlorine dosage in the head works and for effluent disinfection. The plant effluent has consistently been of such quality that the beach waters have shown a coliform index of less than 10 per ml., which is the limit set by the State Department of Public Health for beach waters. With the effective grease removal secured (70 per cent) and removal of suspended solids (generally 75 per cent) there has been no evidence either physical or bacterial of contamination of the beaches west of the Presidio or along the Pacific Ocean beach. It is considered that the present construction program will meet the requirements for prevention of pollution of the shore waters in this area for at least 20 years.

Incidental to the construction of the Richmond-Sunset Plant it was necessary to construct a small pumping plant to pick up the sewage from a residential area lying below the gravity intercepting line from 24th and Lake in the Sea Cliff section. The plant is located on a cliff in close proximity to high class residential development. Effort was expended to make this plant harmonize with the development in the area.

Pumping Plant for Marina

Concurrently with the development of the plant design for the Richmond-Sunset Plant the problem of design of a suitable pumping plant for the Marina District was undertaken. The only practicable available site was in the Marina Park adjacent to the Yacht Harbor. The Park Commission agreed to permit the construction of the plant provided it should be entirely underground. The plant, as constructed, meets this condition. The bottom of the sewage sump is 15.5 ft. below sea level in a filled area originally part of the Pacific International Exposition held in 1915. The structure is a circular unit 55 ft. inside diameter with a middle diaphragm wall. On one side of the division wall are located the pumping unit and controls; the sewage sump occupies the space on the other side. The plant is entered by means of two stairways, one to the sump and the other to the pump room. The stairways are covered by hinged grating doors. The plant is mechanically ventilated through a pipe outlet carried up to simulate a flag pole, which is the only part of the structure above ground.

The pumping plant has a capacity of 25 m.g.d., which represents an allowance of 10 m.g.d. for average sewage flow and 15 m.g.d. for storm-water runoff equivalent to 0.02 in. per hour from the tributary area of 1,043 acres. The pressure line from the plant discharges into a gravity sewer east of Fort Mason and thence to the North Point outfall. It will be carried into the North Plant for treatment under the present design program.

North Point Treatment Plant—General Conditions

After the completion of the program of construction above described, no further work was undertaken until the end of the war. Late in 1944, as a part of a postwar planning program, preliminary design work was begun on the North Point Plant. The firm of Metcalf and Eddy and the writer's office were employed to review the original recommendations for treatment and make such suggestions as were deemed warranted to meet present requirements.

Following a review of the conditions as they presently exist, the conclusion

was reached that the fine screening of the sewage would not adequately meet standards of sewage treatment which would, at an early date, be required before its discharge would be permitted in the waters of the San Francisco Bay. This conclusion antedated by some months the action of the California State Department of Public Health, which on March 11, 1946, adopted a resolution revoking all permits for the discharge of raw sewage into any waters of the state, and set up a degree of minimum treatment requirements which would not be met by fine screening. The upgrading of state requirements indicated that a number of other changes from the original recommendations should be made. The program outlined for the plant provided for grease removal and removal of solids by sedimentation to the degree which has proven satisfactory in the Richmond-Sunset Plant, with digestion of the sludge and disposal of the digested sludge.

The plant location recommended in the original report was considered the only practicable one which could be used. The change in the basic treatment process necessitated a change in the arrangement of the units and an increase in the area required. The site selected is on the west side of Kearny Street, utilizing property on both the north and south sides of Bay Street. A portion of the area provides excellent foundation conditions, some of it in rock. Toward the bay shore, the area is filled, with no solid underlying material within reach by excavation. Plant units in this area will require heavy expenditures for pile supports. With the limited area which could be made available without excessive costs for property acquisition, it was deemed impracticable to provide for sludge digestion and disposal at North Point. The decision was reached that the sludge could be transported by pipe line to a sludge disposal plant site in the industrial area of the city, and that the Southeast Plant could be constructed adjacent to the sludge disposal plant with provision for handling all the sludge from the North Point Plant, the Southeast Plant and a future plant for Visitation Valley. Likewise, the sludge cake from the Richmond-Sunset Plant, the disposal of which has become a problem, could be dried and disposed of along with the sludge from the North Point Plant.

With these major decisions made, the design of the plant has been proceeding for the past year. An important change in the original recommendations is in the effluent discharge line. These recommendations called for a line some 2,300 ft. long into water 50 ft. deep. The existing regulations of the War Department require that no part of any structure in the navigable waters of San Francisco Bay shall be less than 50 ft. below the surface at low tide. This regulation considerably increased the required length of line to reach water of sufficient depth so that the structures would not encroach on the depth clearance. Furthermore, the necessary depth of the outfall line in the slip between the piers would require excavation which might endanger the pier structures. With the degree of treatment recommended, the conclusion was reached that effluent discharge at the pierhead line would meet all requirements for proper disposal. The plans make provision for discharge at the pierhead as later briefly described.

In the following general description of the North Point primary treatment plant, the Cross-Town sludge force lines and the North Point sludge treatment plant at Islais Creek, special emphasis is given to those features of design thought to be relatively new or somewhat of a departure from the more conventional methods of sewage and sludge treatment plant design. All units at each plant will be completely housed in reinforced concrete buildings and provided with forced

draft ventilation as necessary for the control and dissemination of air and gases. At the sludge treatment plant the ventilation air will be exhausted through a 200 ft. high stack in connection with the exhaust gases from the dryers. With the facilities to be provided, it is anticipated that no problem will arise from the location of the plants in proximity to closely built up residential areas.

Design Bases

The present estimated average dry weather sewage flow to the plant is 45 m.g.d., all of which is presently discharged into the slip adjacent to Pier 37. Design average dry weather flow has been set at 65 m.g.d. with hydraulic capacity to handle a maximum rate during storms of 150 m.g.d. All flows in excess of this rate will be diverted direct to the Bay through an existing overflow arrangement with certain modifications.

On the basis of the few days of the winter months when heavy storms occur and when the use of beach areas and shore waters for recreational purposes are at a minimum, it has been deemed impracticable to separate the storm water system or to provide treatment capacity in excess of the 150 m.g.d. rate. In regard to the design dry weather flow of 65 m.g.d., this too has been set as an all time maximum in the sewage program as all dry weather flows in excess of this amount will be intercepted and diverted to the proposed Southeast Plant which will be constructed on a site adjacent to the North Point sludge treatment plant at Islais Creek. This feature of dry weather flow diversion is a natural and feasible arrangement by reason of topographic conditions of the area.

Design population for the plant has been estimated at 835,000 persons, including an allowance for the large number of commuters and a certain amount for industrial waste equivalents. Based upon the design flow of 65 m.g.d., the flow per capita will be 78 gallons.

The area serving the plant comprises all of the downtown business area with its relatively large number of food handling establishments and the densely populated apartment and hotel areas. No great industrial plants, particularly those contributing considerable quantities of industrial waste, are located within the tributary area, therefore the dry weather sewage flow is a comparatively strong domestic sewage of the following characteristics: suspended solids: 400 p.p.m. with 80 per cent volatile; 5-day B.O.D.: 350 p.p.m.; ether soluble matter: 100 p.p.m.

Description of Plant Units

The pretreatment units to be provided will consist of coarse bar racks having 4 in. clear spacing between bars, followed by four rectangular grit removal units, after which will be located mechanically cleaned bar screens having ¾ in. clear spacing between bars. A Parshall flume will be located on the discharge side of each grit tank for quantity measurement and for velocity control between 0.65 and 1.1 ft. per second. The washed grit and screenings will be trucked daily to the municipal sanitary fill operations for disposal along with the city refuse and garbage.

The screened and grit free sewage next flows to the lift station where five centrifugal multispeed pumps driven by synchronous motors will discharge the sewage to the preaeration sedimentation tanks. These pumps will have a combined capacity of 150 m.g.d. and each will discharge through a separate line to the tanks under constant head conditions. This arrangement will eliminate the need for the installation of expensive and sometimes troublesome check and gate valves in the lines.

The six preaeration sedimentation tanks will provide a total displacement period of 2.0 hours at average daily design flow, 0.5 hour of which will be

provided in the preaeration compartments and the remaining 1.5 hours in the sedimentation compartments. The subsidence rate for sedimentation has been set at 1,300 gal. per sq. ft. per day and the overflow weir rate for the axially located multiple effluent launders at 20,000 gal. per lineal foot per day, all based on average daily design flow. Air will be supplied at a rate of from 0.05 to 0.10 cu. ft. per gal. through vertical porous plate diffusers just above the flight collectors in the preaeration compartments. The separation between the preaeration and sedimentation compartments in each tank is accomplished by means of a cross baffle wall extending down from a point just below the normal water surface to a point sufficiently above the tank floor to permit the sludge collectors to travel underneath. All flow between compartments will be underneath the baffle wall. A tilting trough skimmer will be located on top of the baffle wall to act as the top portion of the baffle and to permit skimming from the surface of either tank compartment. The skimming pipes will be fed by surface spray nozzles suspended from the cross walks and using plant effluent for moving floating material from the surface, as now used at the Richmond-Sunset Plant. The sludge removed from the bottom of the tank floor will be deposited at the effluent end by the flights. The arrangement and location of the flights will eliminate any trouble from solids deposition on the floors of the preaeration sections during periods of minimum or no aeration. The overall arrangement also provides a simple means of accomplishing two phases of treatment in one single structure.

Prechlorination for odor control and final chlorination for effluent disinfection will be provided. Initial contact and mixing for final chlorination will be accomplished by means of a circular contact chamber with tangential entry at the surface and with a bottom discharge located in the center of the conically shaped floor. This arrangement creates a vortex flow condition that has proven to be effective.

A Palmer-Bowlus flume will be installed ahead of the chlorine contact chamber for the measurement of flow.

The plant effluent will be discharged into the Bay by means of four lines, two on each of Piers 33 and 35 which are of concrete construction and extend 1,000 ft. off shore. The discharge lines will be carried on the pier structures very close to the water surface and terminate by means of a special outlet structure in a downward bend of 45 degrees in 30 ft. of water. The use of multiple outlets provides a method of distributing the weight on the existing piers and at the same time affords distribution and diffusion of the effluent over a larger area.

Cross-Town Sludge Force Lines

Suspended solids removal in the North Point Plant has been set in the design at 75 per cent, a figure that has been demonstrated to be reasonable by the operation of the existing Richmond-Sunset Plant under similar conditions.

The sludge and grease resulting from the 75 per cent removal of suspended solids will be pumped six miles to the North Point sludge treatment plant. Multispeed motor-driven centrifugal pumps will pump the sludge and grease through two 10-in. diameter lines at velocities between 3.5 and 4.5 ft. per second. The design contemplates pumping sludge and grease containing 2 per cent solids, and this concentration will be carefully maintained at the pumping end. In figuring capacities the lines have been designed to handle the probable amount of ground garbage that will be discharged into the sanitary sewers by the use of home grinders. It has been estimated that this quantity of garbage may eventually amount to 25 per cent of the normal sewage solids.

In the initial operation only one line

is necessary for sludge conveyance. Due to the necessity of providing elutriation water for the sludge treatment plant, plant effluent from North Point will be pumped in the other 10-in. line. After construction of the proposed Southeast Plant, plant effluent will be available from this source for elutriation. At this time, both lines may be called into service for sludge conveyance.

Considerable thought and study have been given to the characteristics of the sludge pumping facilities to maintain a reasonably high coefficient of discharge with a minimum of maintenance. In addition to the usual mechanical cleaning devices for periodic cleaning of the lines, provision will be incorporated for heavy shot dosages of chlorine with accompanying flushings with plant effluent at high velocities, also a type of lining has been specified which will, it is believed, to a great extent eliminate organic growths and slime accumulations.

North Point Sludge Treatment Plant at Islais Creek

The 1 m.g.d. of sludge and grease from North Point will be received at the sludge treatment plant (Figures 3 and 4) and processed through the following treatment plant units, more completely described later: receiving and thickening, digestion, elutriation, ferric chloride conditioning, vacuum filtration and flash drying, with the final product to be sold as a soil conditioner. In addition to the filter cake processed from North Point sludge the flash dryers will handle the filter cake hauled from the Richmond-Sunset Plant.

In addition to the preceding treatment units a waste treatment unit is to be provided for treating the waste liquors or the liquid by-products re-

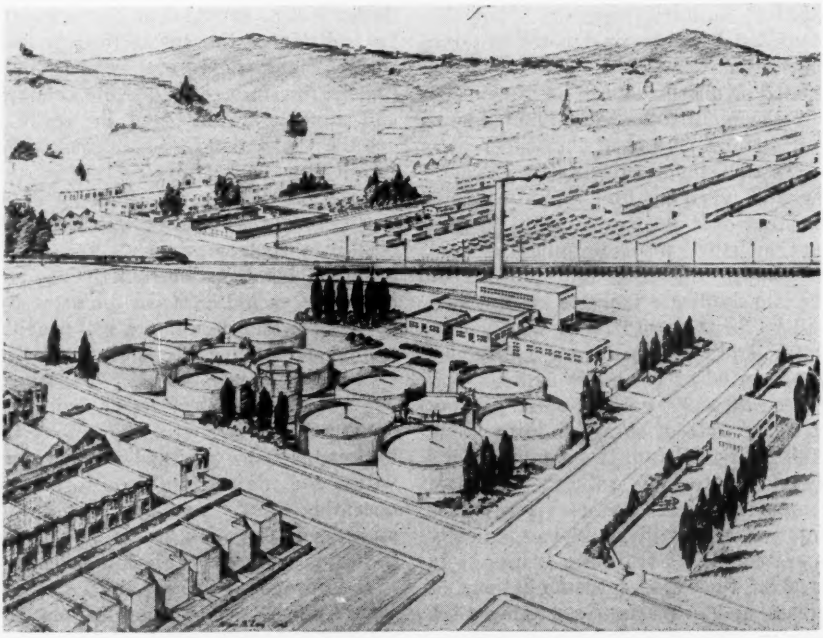


FIGURE 3.—North Point sludge treatment plant, San Francisco, Calif.

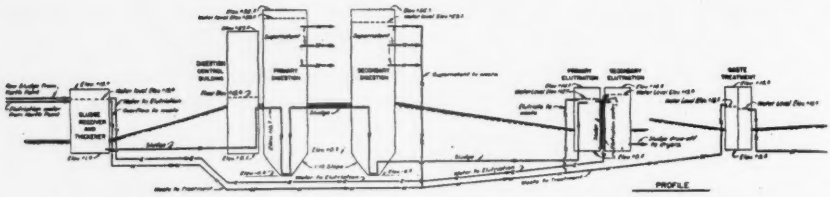


FIGURE 4.—Schematic flow diagram, North Point sludge treatment plant, San Francisco, Calif.

sulting from solids processing. In other plants these wastes are usually, but not without some difficulty, discharged into the plant influent for treatment along with the much greater flow of raw sewage; however, the raw sewage flow for this plant will be treated six miles away at North Point. Therefore, it has been deemed necessary to provide a waste treatment unit to handle a waste liquor flow of 1.5 m.g.d. with a 5-day B.O.D. of some 1,000 p.p.m., and reducing this B.O.D. to the strength of domestic sewage for final disposal without nuisance into the existing sanitary sewers. After the Southeast Plant is constructed to serve this area the waste liquor, either treated or untreated, can be discharged into the plant influent as plant operation dictates as best at that time.

The raw sludge entering the thickening and receiving unit at 98 per cent moisture will be thickened to 96 per cent moisture prior to pumping into the sludge digestion units. Each of the two duplicate tanks to be provided will be 90 ft. by 18 ft. by 12 ft. sidewater depth and will have a displacement period of 2.5 hours and a subsidence rate of 900 gal. per sq. ft. per day at design rate of sludge inflow. Each tank is divided into two compartments by a concrete baffle wall; the upstream compartment will be used for grease flotation and will have mechanically operated flights traveling transversely to skim the surface accumulations of grease and scum into a mixing tank hopper. The flights for removing the settled solids from the tank floors will travel longitudinally toward the influent end of each tank. Sludge and grease will normally be discharged into the mixing tanks where it will be thoroughly mixed by air agitation prior to being pumped to the digestion units. Heavy duty plunger type pumps will be used for this purpose and will discharge through two separate lines to the two digestion control buildings. The overflow or excess moisture from the thickening operation will flow by gravity to the waste treatment unit. Chlorination facilities for periodic or continuous chlorination of the raw sludge will be provided at North Point. In addition to the special design features for the sludge and grease handling in this unit, considerable thought and study were involved in working out the ventilation and exhaust system for an operation of this kind.

After thickening the sludge will be received at the two digestion control buildings each serving its respective group of five digestion tanks. The ten tanks are each 100 ft. in diameter by 30 ft. sidewater depth, and will provide a total detention time of 60 days with an expected volatile solids reduction of 70 per cent. Each tank will be equipped with a floating cover and an interconnected piping arrangement within the control buildings to permit operation of any ratio of primary to secondary digestion that experience indicates most desirable and effective.

It is proposed to heat the tank contents by means of external heaters and heat exchangers located in the control buildings and used in connection with

the sludge recirculation pumps. The supernatant liquor will be discharged at a continuous rate 24 hours per day to the waste treatment unit. Sludge gas will be piped to a relatively small gas-holder followed by a gas booster station for distribution to the dryers, digestion tank heating and the steam boiler for building heating, etc. The low pressure gas piping, boosters, meters, etc., are to be isolated from the other plant buildings in a separate structure to minimize the ever present explosion hazard. The gas requirements for the purposes mentioned will utilize most of the gas produced, and present plans do not contemplate the utilization of any excess. It is expected that with the construction of the proposed Southeast Plant it may be desirable to utilize the excess gas for power generation unless it proves economically feasible to sell the excess gas to the local utility.

Following digestion the sludge from the secondary tanks will be pumped through two lines to the elutriation unit. This unit will include two pair of tanks designed for two stage counter current operation. Each tank will be 16 ft. by 60 ft. by 12 ft. average side-water depth, and will provide a displacement period of 3 hours when combined with 3 volumes of elutriation water (plant effluent pumped from North Point). The waste elutriate from the first stage tanks will be discharged by gravity to the waste treatment unit.

The elutriated sludge from the first stage tanks will be pumped to four sludge and ferric chloride mixing tanks, each feeding one of the four vacuum filters and all located in the same building with the elutriation units. Each mixing tank will feed its respective filter through a short section of straight pipe to avoid the possibility of line clogging by the heavy coagulated sludge. The ferric chloride will be received at the plant in rubber lined tank cars, discharged therefrom to storage and thence to the solution feeders by means of compressed air. The four vacuum filters are each 8 ft. diameter by 14 ft. long; three filters will be used for continuous operation with one as a standby. Design loading for the three in continuous operation, 5 days per week, is 4.5 lb. of dry solids per sq. ft. per hour to produce a total of 200 tons of 72 per cent moisture filter cake per operating day. The filter cake will be transferred to the flash dryers located in the dryer building by means of belt conveyors. At this point the Richmond-Sunset cake will be introduced. The vacuum filter filtrate will be discharged by gravity to the waste treatment unit.

The flash dryer building will house the three drying furnaces and the facilities for storing and loading of the dried sludge. Two of the drying units are designed for continuous operation five days per week, with a third identical unit for standby operation. Each dryer will have an average daily capacity to deliver 30 tons of dried sludge of 8 per cent moisture content. Digestion tank gas will be supplied as fuel for the furnaces. The dried sludge will be delivered by belt conveyor to overhead concrete bins having a week's storage capacity. The sides of these bins will be nearly vertical and the bottoms will be occupied entirely by a system of power driven conveyor screws arranged to form a so-called live bottom. This design will eliminate the possibility of the sludge arching over or hanging up when being withdrawn from the bins. The bins will be arranged for dumping into special closed body trucks, but the layout is such that loading into railroad cars can be done if future conditions justify their use; likewise, the layout permits the future installation of sacking equipment.

The demand for dried sludge for soil conditioning in this area has made it apparent that the demand will absorb all the excess sludge not required by

the city for parks, golf courses, and the like.

All waste liquors from the sludge handling and processing facilities mentioned previously will be received and treated at the waste treatment unit. This unit will provide facilities for the treatment of the combined wastes composed of the excess moisture from thickening, the digestion tank supernatant liquor, the spent elutriate and the vacuum filter filtrate containing some iron salts. The unit will be composed of four rectangular tanks, two of which will be used for violent mixing and aeration and two for final sedimentation. The aeration tanks will be equipped with porous plate vertical diffusers run the full length of each tank, and will provide an aeration period of 2 hours with air applied up to a maximum of 1 cu. ft. per gal. of waste at maximum design rate of flow. The sedimentation tanks will provide 2 hours total displacement period and will be equipped with conventional flight collectors for removing the settled solids from the floors of the tanks to the sludge hoppers located at the influent end. The sludge thus collected will be pumped to the digestion tank system for treatment along with the raw sludge from thickening. The entire unit has been designed to be converted later, with a minimum of modifications, into an elutriation unit to serve the proposed Southeast Plant if conditions at that time justify the conversion.

For administration and control, both the North Point primary treatment plant and the sludge treatment plant will be provided with the necessary bacteriological and chemical laboratories, administrative offices, conference room, machine shop, garage, locker rooms, lunch room for plant personnel, and various other utility rooms.

The city water distribution system supplying each plant will be protected from contamination due to cross connections in the plant system by the installation of a completely separate plant pumping station. This station will provide a means for a physical separation through an air gap between the two distribution systems. Water for supplying drinking fountains, hand and face washing lavatories, and shower baths will be supplied directly from the city mains, all other will be pumped after the separation.

DEVELOPMENTS IN SEWAGE DISPOSAL FOR SAN FRANCISCO—A DISCUSSION

By Ralph G. Wadsworth

City Engineer, City and County of San Francisco, Calif.

Mr. Kennedy's paper is an extremely comprehensive description of the sewage disposal program which has been under way in San Francisco since the first funds were provided by a bond issue of $2,625,000 voted on November 7, 1933. The problem was recognized, however, long before that date. In 1874, the annual report of the City Health Officer contained the following comments on Mission Creek, which then drained the area south of Market Street:

"Few seem to know its extent or its filthiness. From away beyond Eighteenth Street, where it originates in a pond, down past Sixteenth Street, at its intersection with Harrison—the very recollection of which locality by a person who has visited it, is almost sufficient to sicken—to the outlet in Mission Bay and even beyond, it smells to heaven with a loudness and persistence that the strongest nostrils may not withstand, and the disinfectants of a metropolis could not remove."

Mr. Kennedy very properly gives credit to the late C. E. Grunsky for the

first engineering study of San Francisco's sewer system and the first approach to a solution of the disposal problem. Mr. Grunsky was responsible for the preparation of two extensive reports, the first in 1893, describing conditions then existing, and the second in 1899, presenting a complete sewage works plan.

In the latter report Mr. Grunsky listed four possible methods of disposal, namely: dilution by discharge into great bodies of water; chemical treatment; filtration; and application to land for irrigation. He concluded that "the strength and volume of tidal currents, which are available and within such easy reach in the case of this City, are so great, when compared with the volume of sewage, that it is manifest that only the first method of disposal need be considered."

The Grunsky report refers to float observations made by the U. S. Coast Survey in the years 1871 to 1875 and also to later observations made under his own direction in 1893. Based on these observations he designated four prominent points on the San Francisco shore line considered to be safe locations for sewer outfalls, but added the precaution that discharge outlets should be well off shore and in deep water.

A prominent consulting engineer from the East Coast engaged to review the Grunsky report went still further when he reported as follows:

"From the well established data regarding the safe dilution of sewage, it can be readily calculated that under the most favorable conditions the Bay could receive, by a proper dispersion and dilution, the sewage of over 30,000,000 of people without becoming even noticeable. There is, therefore, no question but that the sewage of San Francisco can be properly disposed of into the tide water of the Bay."

How gratifying it would have been to the cities now surrounding the Bay had this prediction proved to be true.

Since the date of the Grunsky report, approximately $18,000,000 have been expended on major sewage works projects in San Francisco including about $3,000,000 for treatment plant land and construction. The additional plants now contemplated, including interceptors and pumping stations, will probably cost in the neighborhood of $15,000,000.

The Marina and Sea Cliff pumping stations mentioned by Mr. Kennedy are in operation on a 24-hour basis. The Richmond-Sunset treatment plant is also in operation in spite of the enlargement work which is now under way.

In closing, attention is directed to the strictly impersonal nature of Mr. Kennedy's presentation. As a matter of fact, he has been in constant personal touch with all of the developments which he describes. The plans for the North Point sludge treatment plant, described at the end of his paper, are being prepared in his office under the terms of an engineering contract with the city. Other design work has been completed or is being performed in the City Engineer's Office under the general direction of H. C. Vensano, Director of Public Works. On all of this work, however, Mr. Kennedy has been employed as consultant and he and his staff have contributed greatly to the results accomplished.

SEWAGE SLUDGE AS A BIOZEOLITE

By C. E. Keefer

Deputy Sewerage Engineer, Bureau of Sewers, Baltimore, Md.

Numerous theories have been advanced to explain the functioning of the activated sludge process. Among these is the one suggested by Theriault (1) (2) (3) (4) (5) that activated sludge is a base-exchanging substance chemically identical with the zeolites used to remove hardness from water. As the writer knew of no further work done to verify Theriault's investigations, experiments were conducted at the Back River sewage treatment plant in Baltimore in order to throw additional light on this problem. Since the solids in activated sludge have many of the same characteristics as the solids in raw and digested sludges, tests were made to see if these two latter materials also had zeolitic characteristics.

Sludges Used

Tests were made using three kinds of sludge; raw, digested and activated. Raw sludge was obtained from mechanically cleaned primary sedimentation tanks treating a fairly strong domestic sewage free from grit and storm water. The digested sludge was drawn from heated digesters, and the activated sludge was collected from aeration tanks with a detention period of approximately 6 hours. The average analyses of these sludges are given in Table I.

TABLE I.—Average Analysis of Sludges

Kind of Sludge	Solids Content (%)	Volatile Solids, Dry Basis, (%)
Raw primary	4–6	80–82
Digested primary	5–6	55–60
Activated	0.75–1.00	80–82

Each of these materials was dried in an oven at 103°C. and then put into a muffle furnace to reduce the volatile content to the values given in Table II.

TABLE II.—Number of Tests Made When Filtering Settled Sewage Through Various Sewage Sludges

Raw Sludge		Digested Sludge		Activated Sludge	
Volatile Matter, Dry Basis, (%)	Number of Tests	Volatile Matter, Dry Basis, (%)	Number of Tests	Volatile Matter, Dry Basis, (%)	Number of Tests
0	4	0	4	0	4
10	4	6	4	15	4
30	6	13	6	27	6
52.1	6	23.6	5	55.3	5

The activated sludge had the highest volatile content of 55.3 per cent. The volatile solids in each of the sludges was reduced in four successive steps until none remained. Tests were made at the end of each step. After drying and removing a portion or all of the volatile matter, the material was in granular form with particle sizes varying from about 1 to 3 mm. Twenty grams of this material was put into a ½-in. glass tube, mounted in an upright position. The average depth of the sludge was about 18⅛ inches.

Description of Experiment

To determine if the sludges had zeolitic properties, varying quantities of primary sedimentation tank effluent, which had been filtered through cotton to remove coarse suspended materials, were allowed to filter through each of the sludges. The ammonia in the influent and in the effluent was determined by nesslerization. After the material was no longer capable of removing ammonia from the sewage, the sludge was regenerated by the application of a 10 per cent NaCl solution and the test was repeated.

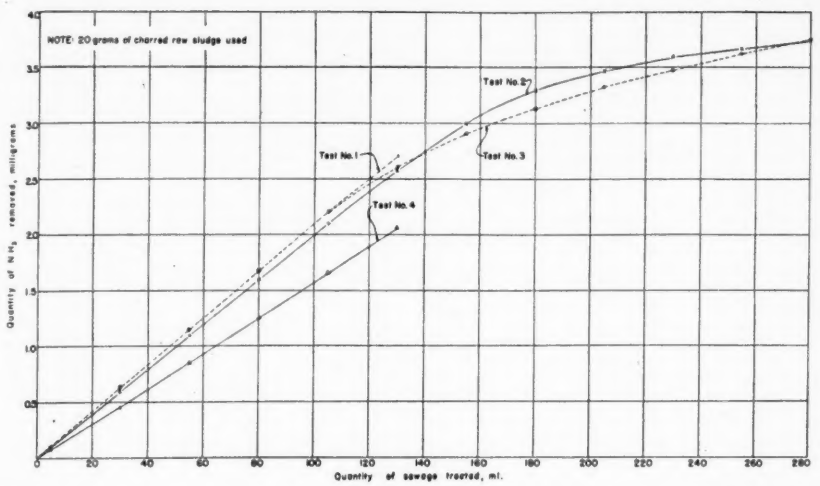

NOTE: 20 grams of charred raw sludge used
Test No. 2
Test No. 1
Test No. 3
Test No. 4
Quantity of NH_3 removed, milligrams
Quantity of sewage treated, ml.

FIGURE 1.—Ammonia removed from sewage by filtering through charred RAW sludge containing 10 per cent volatile matter.

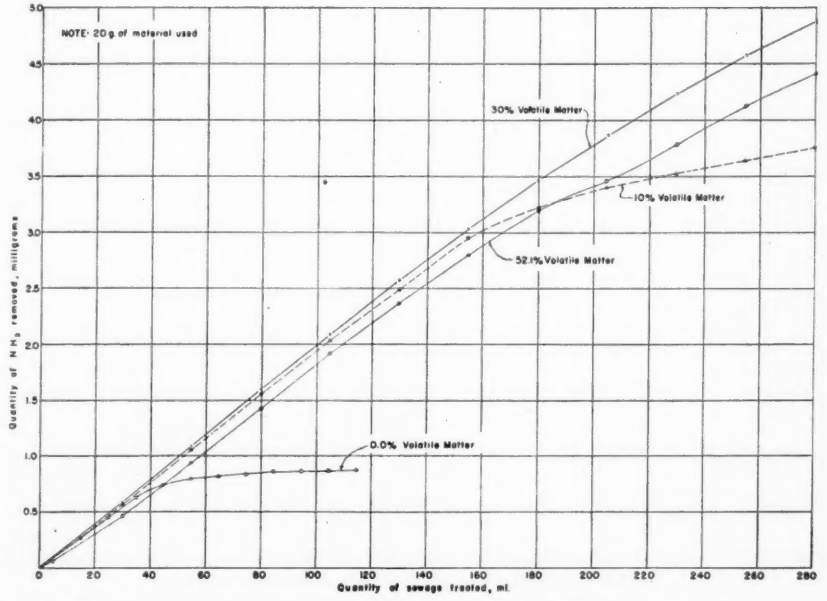

NOTE: 20 g of material used
30% Volatile Matter
10% Volatile Matter
52.1% Volatile Matter
0.0% Volatile Matter
Quantity of NH_3 removed, milligrams
Quantity of sewage treated, ml.

FIGURE 2.—Ammonia removed from sewage by filtering through charred RAW sludge containing varying amounts of volatile matter.

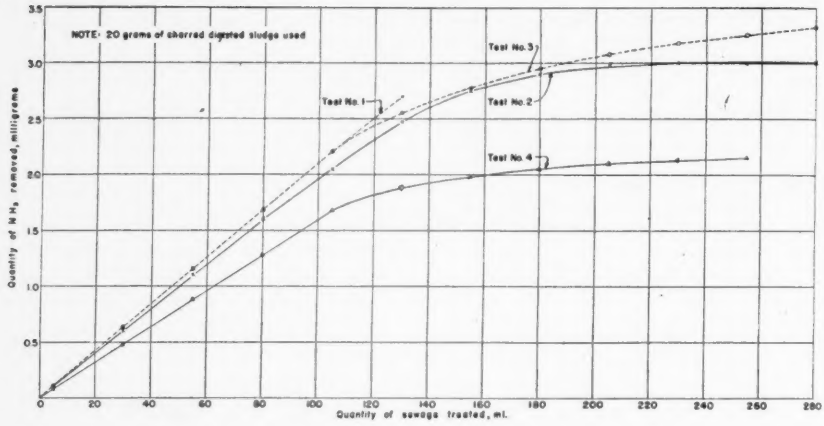

NOTE: 20 grams of charred digested sludge used
Test No. 3
Test No. 1
Test No. 2
Test No. 4
Quantity of NH_3 removed, milligrams
Quantity of sewage treated, ml.

FIGURE 3.—Ammonia removed from sewage by filtering through charred DIGESTED sludge containing 6 per cent volatile matter.

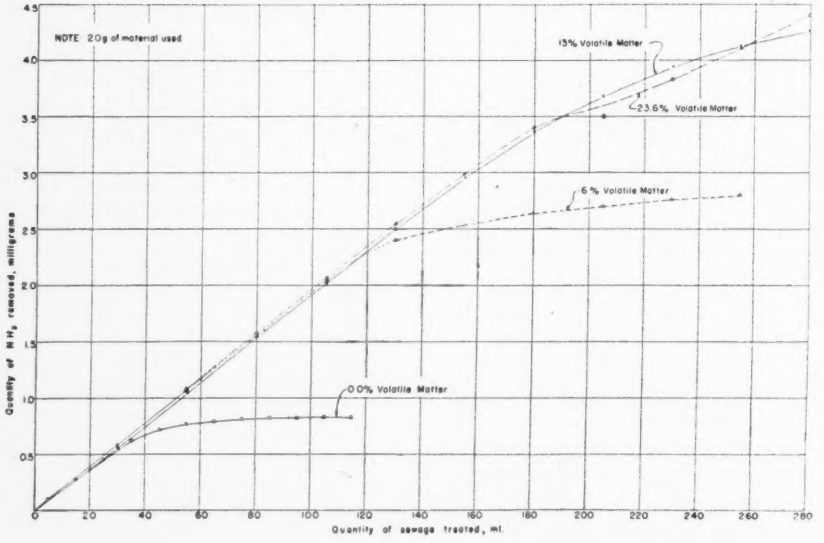

NOTE: 20g of material used
13% Volatile Matter
23.6% Volatile Matter
6 % Volatile Matter
0.0% Volatile Matter
Quantity of NH_3 removed, milligrams
Quantity of sewage treated, ml.

FIGURE 4.—Ammonia removed from sewage by filtering through charred DIGESTED sludge containing varying amounts of volatile matter.

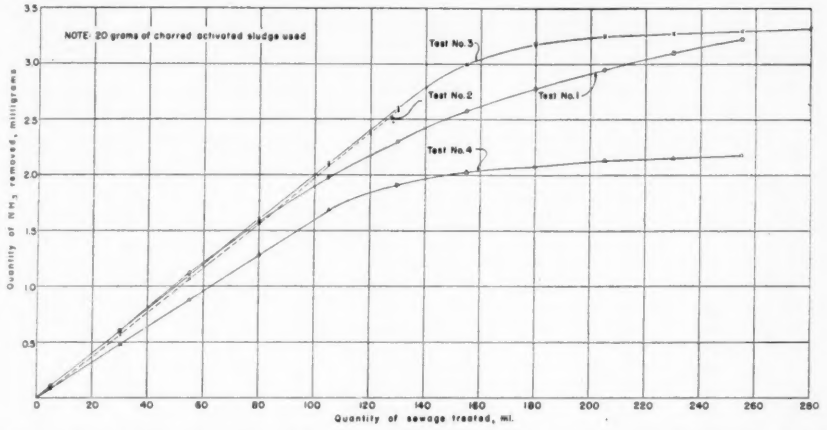


FIGURE 5.—Ammonia removed from sewage by filtering through charred ACTIVATED sludge containing 15 per cent volatile matter.

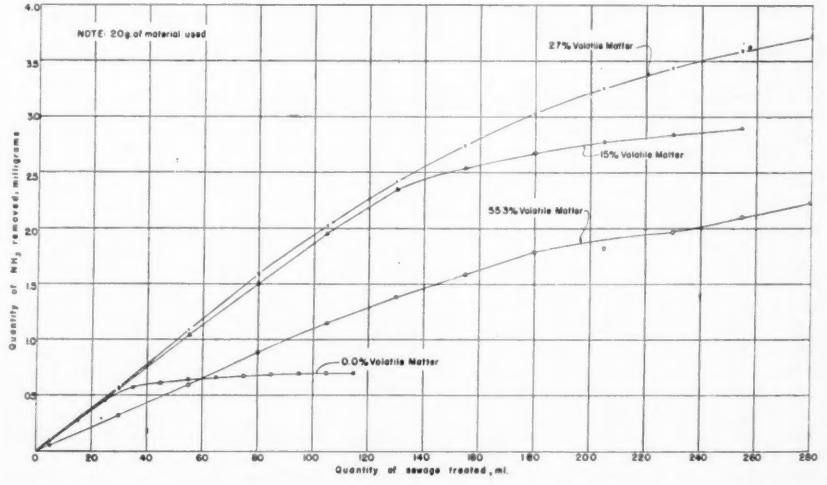


FIGURE 6.—Ammonia removed from sewage by filtering through charred ACTIVATED sludge containing varying amounts of volatile matter.

TABLE III.—Ammonia Removed by Filtering Settled Sewage Through Raw Sludge Solids Containing 10 Per Cent Volatile Matter

Quantity of Sewage Treated		Test 1 (21 p.p.m. NH_3 in applied sewage)		Test 2 (20 p.p.m. NH_3 in applied sewage)		Test 3 (21 p.p.m. NH_3 in applied sewage)		Test 4 (16 p.p.m. NH_3 in applied sewage)	
		NH_3 Removed		NH_3 Removed		NH_3 Removed		NH_3 Removed	
Ml.	Summation (ml.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)
5	5	20	0.100	19	0.095	20	0.100	16	0.080
25	30	21	0.625	20	0.595	21	0.625	15	0.455
25	55	21	1.150	20	1.095	21	1.150	16	0.855
25	80	21	1.675	20	1.595	21	1.675	16	1.255
25	105	21	2.200	20	2.095	21	2.200	16	1.655
25	130	20	2.700	19	2.570	16	2.600	16	2.055
25	155	—	—	17	2.995	12	2.900	—	—
25	180	—	—	12	3.295	9	3.125	—	—
25	205	—	—	7	3.470	8	3.325	—	—
25	230	—	—	5	3.595	6	3.475	—	—
25	255	—	—	3	3.670	6	3.625	—	—
25	280	—	—	3	3.745	5	3.750	—	—
25	305	—	—	—	—	5	3.875	—	—
25	330	—	—	—	—	4	3.975	—	—

TABLE IV.—Ammonia Removed by Filtering Settled Sewage Through Raw Sludge Solids Containing 52.1 Per Cent Volatile Matter

Quantity of Sewage Treated		Test 1 (22 p.p.m. NH_3 in applied sewage)		Test 2 (22 p.p.m. NH_3 in applied sewage)		Test 3 (19 p.p.m. NH_3 in applied sewage)		Test 4 (19 p.p.m. NH_3 in applied sewage)		Test 5 (24 p.p.m. NH_3 in applied sewage)		Test 6 (19 p.p.m. NH_3 in applied sewage)	
		NH_3 Removed		NH_3 Removed		NH_3 Removed		NH_3 Removed		NH_3 Removed		NH_3 Removed	
Ml.	Summation (ml.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)
5	5	17	0.085	22	0.110	18	0.090	17	0.085	0	0.000	17	0.085
25	30	17	0.510	22	0.660	18	0.540	17	0.510	3	0.075	18	0.535
25	55	17	0.935	22	1.210	19	1.015	14	0.860	21	0.600	19	1.010
25	80	17	1.360	22	1.760	19	1.490	16	1.260	23	1.175	19	1.485
25	105	17	1.785	22	2.310	19	1.965	16	1.660	24	1.775	19	1.960
25	130	16	2.185	19	2.785	19	2.440	11	1.935	24	2.375	19	2.435
25	155	14	2.535	17	3.210	19	2.915	11	2.210	24	2.975	19	2.910
25	180	14	2.885	13	3.535	19	3.390	7	2.385	24	3.575	19	3.385
25	205	14	3.235	11	3.810	19	3.865	6	2.535	—	—	19	3.860
25	230	14	3.585	6	3.960	19	4.340	5	2.660	—	—	19	4.335
25	255	—	—	6	4.110	19	4.815	3	2.735	—	—	19	4.810
25	280	—	—	6	4.260	19	5.290	3	2.810	—	—	19	5.285
25	305	—	—	4	4.360	17	5.715	—	—	—	—	19	5.760
25	330	—	—	—	—	11	5.990	—	—	—	—	19	6.235

TABLE V.—Ammonia Removed by Filtering Settled Sewage Through Digested Sludge Solids Containing 6 Per Cent Volatile Matter

Quantity of Sewage Treated		Test 1 (21 p.p.m. NH_3 in applied sewage)		Test 2 (20 p.p.m. NH_3 in applied sewage)		Test 3 (21 p.p.m. NH_3 in applied sewage)		Test 4 (16 p.p.m. NH_3 in applied sewage)	
		NH_3 Removed		NH_3 Removed		NH_3 Removed		NH_3 Removed	
Ml.	Summation (ml.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)
5	5	21	0.105	20	0.100	21	0.105	16	0.080
25	30	21	0.630	20	0.600	21	0.630	16	0.480
25	55	21	1.155	20	1.100	21	1.155	16	0.880
25	80	21	1.680	20	1.600	21	1.680	16	1.280
25	105	21	2.205	18	2.050	21	2.205	16	1.680
25	130	20	2.705	17	2.475	14	2.555	8	1.880
25	155	—	—	11	2.750	9	2.780	4	1.980
25	180	—	—	6	2.900	7	2.955	3	2.055
25	205	—	—	2	2.950	5	3.080	2	2.105
25	230	—	—	1	2.975	4	3.180	1	2.130
25	255	—	—	1	3.000	3	3.255	1	2.155
25	280	—	—	1	3.025	3	3.330	—	—
25	305	—	—	—	—	3	3.405	—	—
25	330	—	—	—	—	2	3.455	—	—

TABLE VI.—Ammonia Removed by Filtering Settled Sewage Through Digested Sludge Solids Containing 23.6 Per Cent Volatile Matter

Quantity of Sewage Treated		Test 1 (22 p.p.m. NH_3 in applied sewage)		Test 2 (19 p.p.m. NH_3 in applied sewage)		Test 3 (19 p.p.m. NH_3 in applied sewage)		Test 4 (24 p.p.m. NH_3 in applied sewage)		Test 5 (19 p.p.m. NH_3 in applied sewage)	
		NH_3 Removed		NH_3 Removed		NH_3 Removed		NH_3 Removed		NH_3 Removed	
Ml.	Summation (ml.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)
5	5	17	0.085	19	0.095	19	0.095	24	0.12	19	0.095
25	30	18	0.535	19	0.570	16	0.495	24	0.72	19	0.570
25	55	19	1.010	19	1.045	18	0.945	24	1.32	19	1.045
25	80	20	1.510	19	1.520	18	1.395	24	1.92	19	1.520
25	105	19	1.985	19	1.995	18	1.845	24	2.52	19	1.995
25	130	17	2.410	19	2.470	16	2.245	24	3.12	19	2.470
25	155	15	2.785	19	2.945	13	2.570	24	3.72	19	2.945
25	180	10	3.035	19	3.420	9	2.795	24	4.32	19	3.420
25	205	8	3.235	19	3.895	8	2.995	—	—	19	3.895
25	230	6	3.385	19	4.370	7	3.170	—	—	19	4.370
25	255	4	3.485	19	4.845	5	3.295	—	—	19	4.845
25	280	3	3.560	19	5.320	5	3.420	—	—	19	5.320
25	305	3	3.635	18	5.770	—	—	—	—	19	5.795
25	330	—	—	18	6.220	—	—	—	—	19	6.270

TABLE VII.—Ammonia Removed by Filtering Settled Sewage Through Activated Sludge Solids Containing 15 Per Cent Volatile Matter

Quantity of Sewage Treated		Test 1 (21 p.p.m. NH_3 in applied sewage)		Test 2 (21 p.p.m. NH_3 in applied sewage)		Test 3 (20 p.p.m. NH_3 in applied sewage)		Test 4 (16 p.p.m. NH_3 in applied sewage)	
		NH_3 Removed		NH_3 Removed		NH_3 Removed		NH_3 Removed	
Ml.	Summation (ml.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)
5	5	20	0.100	17	0.085	20	0.100	16	0.080
25	30	20	0.600	19	0.560	20	0.600	16	0.480
25	55	21	1.125	20	1.060	20	1.100	16	0.880
25	80	18	1.575	20	1.560	20	1.600	16	1.280
25	105	16	1.975	21	2.085	20	2.100	16	1.680
25	130	13	2.300	20	2.585	20	2.600	9	1.905
25	155	11	2.575	—	—	16	3.000	5	2.030
25	180	8	2.775	—	—	7	3.175	2	2.080
25	205	7	2.950	—	—	3	3.250	2	2.130
25	230	6	3.100	—	—	1	3.275	1	2.155
25	255	5	3.225	—	—	1	3.300	1	2.180
25	280	—	—	—	—	1	3.325	—	—

TABLE VIII.—Ammonia Removed by Filtering Settled Sewage Through Activated Sludge Solids Containing 27 Per Cent Volatile Matter

Quantity of Sewage Treated		Test 1 (24 p.p.m. NH_3 in applied sewage)		Test 2 (19 p.p.m. NH_3 in applied sewage)		Test 3 (24 p.p.m. NH_3 in applied sewage)		Test 4 (20 p.p.m. NH_3 in applied sewage)		Test 5 (19 p.p.m. NH_3 in applied sewage)		Test 6 (19 p.p.m. NH_3 in applied sewage)	
		NH_3 Removed		NH_3 Removed		NH_3 Removed		NH_3 Removed		NH_3 Removed		NH_3 Removed	
Ml.	Summation (ml.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)	P.P.M.	Summation (mg.)
5	5	21	0.105	19	0.095	23	0.115	19	0.095	17	0.085	15	0.075
25	30	20	0.605	19	0.570	23	0.690	19	0.570	19	0.560	16	0.475
25	55	24	1.205	19	1.045	24	1.290	20	1.070	19	1.035	17	0.900
25	80	22	1.755	19	1.520	24	1.890	20	1.570	18	1.485	16	1.300
25	105	20	2.255	16	1.920	20	2.390	17	1.995	16	1.885	16	1.700
25	130	20	2.755	15	2.295	18	2.840	14	2.345	13	2.210	13	2.025
25	155	19	3.230	13	2.620	14	3.190	13	2.670	10	2.460	11	2.300
25	180	17	3.655	11	2.895	11	3.465	11	2.945	7	2.635	10	2.550
25	205	15	4.030	9	3.120	9	3.690	8	3.145	6	2.785	7	2.725
25	230	13	4.355	7	3.295	8	3.890	6	3.295	5	2.910	6	2.875
25	255	10	4.605	5	3.420	7	4.065	5	3.420	4	3.010	5	3.000
25	280	9	4.830	4	3.520	6	4.215	4	3.520	3	3.085	5	3.125
25	305	8	5.030	4	3.620	5	4.340	4	3.620	2	3.135	4	3.225
25	330	6	5.180	—	—	5	4.465	3	3.695	—	—	—	—
25	355	6	5.330	—	—	4	4.565	3	3.770	—	—	—	—

Results

Due to the lack of space only a portion of the more pertinent data is given (Figures 1 to 6 and Tables III to VIII).

Table III and Figure 1 give the quantities of ammonia removed from the sewage when filtering the material through raw sludge solids containing 10 per cent of volatile matter. Four tests or filtration cycles were made. At the end of each cycle the sludge was reactivated with sodium chloride. These tests indicate that it was possible to remove from 2.0 to 2.5 mg. of ammonia before an appreciable quantity was present in the effluent. This amount is equivalent to 100 to 125 mg. per 1,000 grams of sludge. The greatest removal was obtained during Test 3 when 3.975 mg. was removed from 330 ml. of sewage.

Table IV gives another group of tests using raw sludge containing 52.1 per cent volatile matter. In this group the sewage was filtered six times. During Test 6 of this series 6.235 mg. of ammonia was removed from 330 ml. of sewage. At the termination of this test there was no indication that the sludge had lost its power of removing ammonia from the sewage.

Figure 2 shows the amount of ammonia removed when using raw sludge containing various amounts of volatile matter. Each of the curves gives the average results for each group of tests when using sludge with a volatile solids content as shown. These tests indicate that the sludge devoid of volatile matter was least effective in removing ammonia. The sludge containing 30 per cent volatile matter gave the best results.

Table V and Figure 3 give the amounts of ammonia removed from sewage when brought in contact with digested sludge containing 6 per cent of volatile matter. Four tests or filtration cycles were made. During Test 3 of this series 3.455 mg. of ammonia was removed from 330 ml. of sewage. Table VI gives the quantities of ammonia removed from the digested sludge containing 23.6 per cent of volatile matter. High removals were obtained during the second and the fifth tests. A summary of the results when using digested sludge containing varying amounts of volatile matter is given in Figure 4. As was the case with the raw sludge, only a small amount of ammonia was removed by the sludge from which all of the volatile matter had been removed. The best removals were obtained when using sludges that had 13 and 23.6 per cent of volatile matter.

The results when using activated sludge are given in Tables VII and VIII and Figures 5 and 6. In general the removal of ammonia was the same as when raw and digested sludges were used except that the amounts were somewhat less.

Discussion and Conclusions

All three of the sludges were capable of removing ammonia from sewage. This ability decreased in inverse proportion to the amount removed. In every instance it was possible to reactivate the sludge many times with sodium chloride. Raw sludge was the most effective in removing ammonia; digested sludge gave the next best results; activated sludge was the least effective.

The inorganic residues remaining after all of the volatile solids were driven off from the three sludges were about equally effective in removing ammonia. The presence of comparatively small amounts of volatile matter considerably increased the amount of ammonia removed. The ability to remove ammonia resided more in the volatile material than in the fixed solids.

The removal of only 100 to 125 mg. of ammonia from sewage per 1,000 grams of solids (0.1 to 0.125 lb. per 1,000 lb.) indicates that the action of activated sludge as a zeolite is of negli-

gible value. By the time raw sewage solids enter aeration tanks, they frequently have been in contact with the sewage for hours and will have taken up most or all of the ammonia possible. No doubt as these solids pass through the aeration tanks they become more finely divided by the agitation of air. New interfaces are thus produced between the solids and the sewage, permitting a base exchange of ammonium ions.

If it is assumed, however, that the suspended solids entering an aeration tank exclusive of the return activated sludge (this material will have taken up all the ammonium ions possible during its previous passages through the aeration tanks) amounts to 150 p.p.m., and each 1,000 lb. of these solids can remove 0.125 lb. of NH_3, 0.156 lb. of NH_3 per million gallons of sewage or 0.02 p.p.m. would be removed. As the amount of NH_3 normally removed by the activated sludge process varies from about 10 to 20 p.p.m., it is apparent that the removal of ammonia is largely due to causes other than a base-exchange reaction.

Acknowledgments

The Back River sewage works, where this investigation was made, is under the general supervision of Nathan L. Smith, Director, Department of Public Works, and John J. Hunt, Sewerage Engineer, with R. J. Trautmen, Associate Engineer.

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OXIDATION OF REDUCED SULFUR COMPOUNDS IN SEWAGE*

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Sulfur in sewage is present in either organic or inorganic forms. The organic sulfur in sewage is extremely low (0.2 p.p.m.) according to Elder and Buswell (1). The inorganic sulfur is mostly in the form of sulfates.

The sulfate content of domestic sewage varies according to geological and resultant soil formations from which the water supply is derived. The sulfate content of domestic sewage in certain regions may be as high as 200 to 300 p.p.m. and in others it may be as low as 20 to 40 p.p.m.

There are indications that organic sulfur and sulfates do not represent all the sulfur in sewage. In septic sewage a part of the sulfate is reduced to sulfides; in addition Pomeroy and Bowlus (2) indicate that thiosulfates might also be present (up to 10 p.p.m).

The quantity of sulfur and the type of sulfur compounds present in sewage are greatly modified by the presence of industrial wastes. Many industries contribute large quantities of sulfates either in the form of acids or combined with different cations; furthermore, sulfur dioxide, thiosulfates, sulfites, and sulfides may be discharged by various industrial processes.

Little is known as to the effect of these sulfur compounds on sewage treatment processes and their relative rate of oxidation. Information regarding the effect of various forms of reduced sulfur compounds on the oxidation processes is meager. This paper reports on studies of the rates of oxidation of sulfur compounds under aerobic conditions.

Methods

The sulfur compounds selected for study were sodium sulfite, sodium sulfide, sodium acid sulfite, sodium thiosulfate, sulfur dioxide and hydrogen sulfide. The first four of these compounds were used in 100 p.p.m. concentrations as S, the last two in 10 p.p.m. concentrations as S. The first four compounds were added to (*a*) sewage, (*b*) heat sterilized sewage, (*c*) an activated sludge-sewage mixture containing 1,000 p.p.m. suspended solids, and (*d*) sewage containing 1,000 p.p.m. of trickling filter slime. These various mixtures were aerated with diffused air. Portions were removed at intervals, and after the sludge was settled, sulfates were determined. Aseptic methods were used to maintain sterility of the heat sterilized series during aeration.

Aeration could not be used for sulfur dioxide and hydrogen sulfide because these gases would be liberated and lost. Hence it was necessary to study their oxidation under quiescent conditions. In order to maintain dissolved oxygen during the period of quiescent incubation, the concentration of these compounds had to be lowered to 10 p.p.m. Water instead of sewage was used as a substrate. The dissolved oxygen of the water and oxygen supplied from surface reaeration under quiescent conditions maintained an aerobic condition. The oxidation of these compounds could not be studied, for the same reason, in the presence of biologically active materials such as activated sludge and trick-

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ling filter slime. The oxidation of these compounds was, therefore, determined by using water as a menstruum with and without 1 ml. per liter of sewage as inoculum.

The oxidation of the sulfur compounds used, with the exceptions noted below, was determined by measurement of the increase in sulfate content. In each series a control run was made of the sterilized and non-sterile sewage, and the increase in sulfates was determined during the incubation period. The sulfates in the controls were subtracted from the sulfates in the mixtures to which artificial additions of sulfur compounds were made for the corresponding periods and series. The increase in sulfates thus obtained was attributed to the oxidation of the added sulfur compounds.

Sulfates were, at first, determined by the usual method of precipitation with barium chloride from acid solution. As some of the reduced forms of sulfur, added artificially, were also precipitated by this method, the procedure was changed so that only sulfates were included in the precipitation. With the benzidine hydrochloride method, sulfites, sulfides, and bisulfites are not precipitated. The results reported in this paper are based on the use of the benzidine hydrochloride method whenever the presence of these interfering sulfur compounds necessitated its use.

Since thiosulfates interfere with the benzidine hydrochloride method, the oxidation of this compound was studied by measuring the loss of thiosulfate by the iodine titration method. Similarly, the loss of the added hydrogen sulfide and sulfur dioxide was measured by the iodine titration method.

The accuracy of the benzidine method for sulfate determination was checked by the addition of known amounts of sulfates to sewage. The recovery was within + 2.4 per cent and − 3.4 per cent in triplicate determinations with a total sulfate content of 195 p.p.m.

Results

Coincident with the studies on the oxidation of added sulfur compounds, analyses were made on the total sulfur and sulfate contents of a number of sewages from different plants in New Jersey. These sewages were of strictly domestic origin and in a fresh condition.

TABLE I.—Total Sulfur and Sulfate Contents of Sewage

Sewage No.	Sulfate Sulfur (p.p.m.)	Total Sulfur (p.p.m.)	Non-sulfate Sulfur (p.p.m.)
1	24.0	30.1	5.5
2	26.0	35.9	9.9
3	23.7	31.6	7.9
4	24.3	28.4	4.1
5	27.5	39.4	11.9
6	33.1	44.6	11.5
7	38.4	49.5	11.1
Ave.	28.2	37.1	8.9

The results are assembled in Table I. The sulfate content varied from 24.3 to 38.4 p.p.m., expressed as S, with an average of 28.2 p.p.m. sulfur in the form of sulfate. Total sulfur varied from 28.4 p.p.m. to 49.5 p.p.m. with an average of 37.1 p.p.m. expressed as S. The difference between the total sulfur and sulfate sulfur represents sulfur in forms other than sulfate. A small portion of this non-sulfate S is in organic form and the remainder is inorganic sulfides, sulfites, thiosulfates, etc., which represent the forms of sulfur which might be subject to oxidation. The quantity of this form of sulfur varied from 4.1 to 11.9 p.p.m., with an average of 8.9 p.p.m. expressed as S.

The quantities of sulfur compounds in domestic sewage subject to potential oxidation are therefore small, and the experiments designed to show the rate of oxidation of this component normally occurring in sewage are subject

TABLE II.—Oxidation of Sulfur in Sewage Upon Aeration

Aeration Period (days)	Sulfate Sulfur (p.p.m.)							
	Non-Sterile				Sterile			
0	24.6	26.0	23.7	24.3	24.6[1]	26.05	23.7	24.3
1	25.9	36.4	32.3	27.9	24.9	37.6	28.3	27.5
2	25.2	37.1	31.9	27.5	24.8	37.9	30.3	27.9
3	30.3	—	—	—	30.8	—	—	—
4	—	—	32.3	—	—	—	32.7	—
5	—	—	—	28.2	—	—	—	28.1
6	30.4	—	—	—	30.7	—	—	—
7	30.1	—	—	28.2	30.4	—	—	28.2
Max. increase in sulfate S	5.8	11.1	8.6	3.9	5.8	11.9	9.0	3.9
Non-sulfate S originally present	5.5	9.9	7.9	4.1	5.5	9.9	7.9	4.1

[1] Sterilized with formaldehyde; all others heat sterilized.

to some experimental error because of the small quantities involved.

The results of a number of tests with sterilized and non-sterile sewage, assembled in Table II, show that upon aeration a consistent increase in sulfate content is obtained, indicating the oxidation of the reduced forms of sulfur originally present in sewage either in organic or inorganic forms. It is of interest to note that within the aeration periods employed the maximum increase in sulfates is at least equal to the non-sulfate sulfur originally present in the sewage, indicating a complete recovery and oxidation. On occasions the increase in sulfate is higher than the original oxidizable sulfur content of the sewage, which is to be attributed to experimental errors; the discrepancy is not in excess of 1 to 2 p.p.m. It is also to be noted that the oxidation of the sulfur compounds in sewage was nearly as complete under sterile conditions as in the presence of bacteria. It appears that the oxidation of these reduced sulfur compounds native to sewage can take place chemically.

The oxidation of 100 p.p.m. of artificially added reduced sulfur compounds, when aerated with sterilized and non-sterile sewage and in the presence of biologically active material, is shown in Figure 1. The results are presented as percentages of added sulfur oxidized after allowance has been made for the oxidation of sulfur compounds native to sewage.

The results indicate that sodium sulfite, sodium sulfide, and sodium acid sulfite are oxidized as rapidly in sterile sewage as in non-sterilized sewage when an ample supply of oxygen is present. Sodium thiosulfate is not oxidized, however, in the absence of microorganisms. The addition of biologically active material increased the rate of oxidation of each of these compounds.

It appears that the oxidation in the sewage may be chemical because of the paucity of the proper oxidizing flora. In the presence of an established specialized flora the oxidation is mainly biochemical and proceeds at a higher rate. Within 5 to 10 hours the oxidation is nearly complete.

The difference in the flora in the activated sludge and trickling filter slime in inducing the oxidation of these compounds does not seem significant. In the case of sodium thiosulfate the effect of biologically active material in increasing the rate of oxidation over

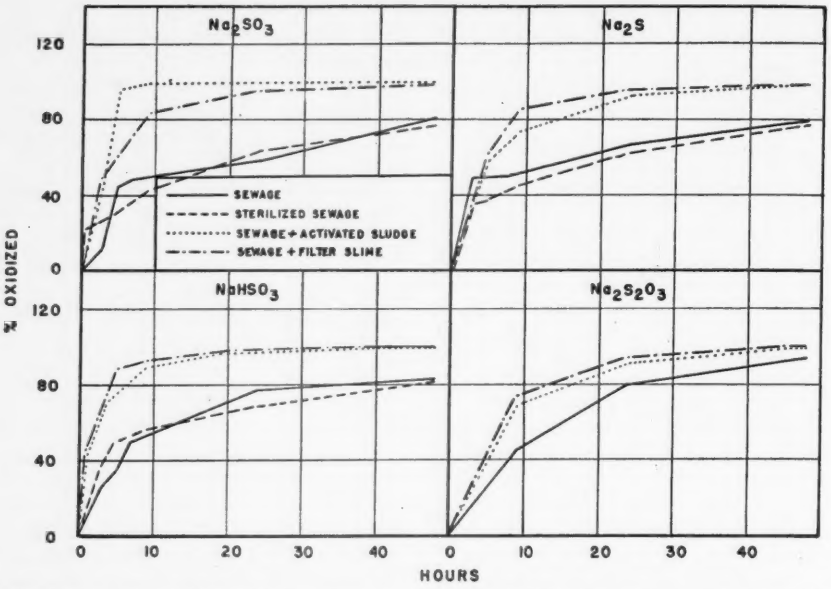

FIGURE 1.—Comparison of the rates of oxidation of 100 p.p.m. (expressed as S) of sulfite, sulfide, acid sulfite and thiosulfate of sodium, upon aeration with sewage.

that obtained by sewage organisms is not so great as with the other compounds.

The rates of oxidation of hydrogen sulfide and sulfur dioxide are graphically shown in Figure 2. These materials were added in 10 p.p.m. concentration to water. In one series no inoculum was introduced and in the other 1 ml. of sewage was added per liter. Both were kept under quiescent conditions with only surface reaeration.

The method of approach using water as a substrate and low concentrations of these compounds was necessitated by the volatile nature of the gases. Since the oxidation is measured by the disappearance of these substances rather than by the formation of sulfates, the possibility that a part of the gases were lost to the atmosphere rather than actually oxidized, is not ruled out. With these precautions it seems that hydrogen sulfide disappears from solution at about the same rate as sulfide, sulfite or acid sulfite. The similarity of the rates adds to the plausibility of an actual oxidation, since the sulfides and sulfites could not be lost by volatilization. The fact that the rate of disappearance of sulfide is the same with and without seeding points toward a chemical oxidation of this compound. It is possible that seeding might have been inadequate both qualitatively and quantitatively, but apparent oxidation took place.

Sulfur dioxide disappeared at a reduced rate as compared with hydrogen sulfide. The oxidation of SO_2 also appears to be chemical.

Discussion

The study was designed to determine the rate of oxidation of a number of reduced inorganic sulfur compounds in sewage, simulating the conditions of aerobic treatment. No information has been obtained on the effect of sulfides, sulfites, thiosulfate, and sulfur dioxide

on the aerobic treatment processes. Information is needed regarding the effect of various concentrations of these compounds on the purification effected by activated sludge and trickling filters. The effect on the condition of the activated sludge would be of interest.

These different sulfur compounds are discharged in a number of industrial wastes in varying quantities. The limit of tolerance of biological treatment processes toward these compounds needs to be determined. The possibility of developing a special flora and fauna capable of coping with these materials is of interest from the standpoint of their separate treatment.

This study is, therefore, only a partial answer to the problem. It shows that sulfur compounds are readily oxidized in sewage. The oxidation may be chemical or biochemical depending upon the presence or absence of a specialized oxidizing flora as is found in activated sludge or trickling filter slime. Sewage does not seem to have such an active flora because the rates of oxidation are nearly alike in sterile and non-sterile sewage.

Of the compounds used thiosulfate is the only one that cannot be oxidized without bacteria. The rate of oxidation of sulfur dioxide is the slowest of all, but this might be due to the exigencies of experimental conditions which precluded the use of an active flora. Hydrogen sulfide under similar conditions of poor seeding oxidized as rapidly as the sulfides and sulfites in the presence of adequate sewage organisms.

Elder and Buswell (1), approaching the problem from the standpoint of the oxygen demand of a number of sulfur compounds, concluded that the

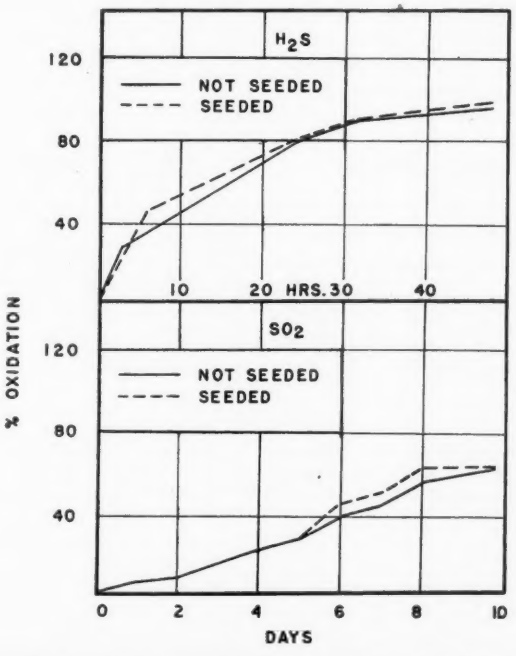

FIGURE 2.—The oxidation of 10 p.p.m. of hydrogen sulfide and sulfur dioxide (expressed as S) in seeded and unseeded water solutions.

oxygen demand of sodium sulfocyanate may be biochemical. The oxidation of other compounds such as thiosulfate, metabisulfite, sulfite and sulfide is more chemical than biochemical because of the rapid rate of oxygen consumption.

In fresh domestic sewage there are small and variable quantities of reduced sulfur compounds. The quantity varies from 4 to 12 p.p.m. with an average of 9.0 p.p.m. in the sewages tested. Only a small portion of this is organic sulfur. Since the sewages used were fresh and of strictly domestic origin, the likelihood of appreciable percentages of the reduced sulfur compounds being due to sulfides is small. It seems probable that the reduced sulfur compounds present in sewage are in the forms of sulfites, thiosulfates and thionates.

The oxidation rate of these native reduced sulfur compounds corresponds to that of the selected group of sulfur compounds artifically added to sewage. Both types of mixtures are oxidized completely under aerobic conditions; they are also oxidized under sterile and non-sterile conditions.

Summary and Conclusions

Sodium salts of sulfide, sulfite, acid sulfite, and thiosulfate were added in 100 p.p.m. concentrations to sewage, the normal flora of which was artificially modified by adding biologically active material such as activated sludge or trickling filter slime, or completely destroyed by heat sterilization. These mixtures were aerated with diffused air. The increase of sulfates in comparison with controls was used as an indication of oxidation. With hydrogen sulfide and sulfur dioxide, the above method was modified by precluding artificial aeration, by maintenance of the materials under quiescent conditions, and by use of water as a substrate. Biologically active slime could not be added. Comparisons were made between seeding with 1 ml. of sewage per liter and without seed. The oxidation was measured by the rate of disappearance of these compounds.

The results show the following:

(1) Fresh domestic sewage contains an appreciable quantity of reduced sulfur compounds.

(2) These compounds, native to fresh domestic sewage, are oxidized completely by aeration whether under sterile or non-sterile conditions. This characteristic suggests that the reduced sulfur compounds in sewage are not organic in nature.

(3) The artificially added sulfur compounds (with the exception of thiosulfate) were readily oxidized in sewage under sterile conditions.

(4) The rate of oxidation was enhanced in the presence of the biologically active flora of activated sludge and trickling filter slime.

(5) The rate of oxidation of sulfur dioxide was the lowest of all the compounds tested under the conditions of the experiment.

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NITRIFICATION AND B.O.D.*

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In his discussion of B.O.D. in "Stream Sanitation" Phelps (1) makes note of the fact that when "nitrification begins to assert itself, it frequently requires oxygen in considerably greater quantity than is required during the first stage (B.O.D.) and sometimes complicates the determination of the first stage B.O.D." This fact has been recognized by Adeney (2), Theriault (3) and others in their studies on B.O.D. of polluted waters and industrial wastes.

Mohlman (4) has called attention to the fact that in determining B.O.D. on activated sludge or trickling filter effluents which may be in a stage of active nitrification, values are obtained which are misleading as regards the degree of stabilization of the effluents. Abbot (5) was made aware of this effect in his work with stabilized effluents and attempted to correct it by using the values obtained after 2 or 3 day incubation periods.

More recently Sawyer and Bradney (6) reported on this effect at Sioux Falls. They recognize, as did the earlier investigators, that these high values are the result of nitrogenous oxidation which has superimposed itself over the small residual carbonaceous B.O.D remaining in the effluent. Sawyer and Bradney suggest that such effluents be pasteurized before determination as a corrective measure, and the results of their experiments indicate that pasteurization does not affect the carbonaceous stage of the B.O.D. test.

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Sanitary District Experience

As far back as 1934, the influence of nitrifying organisms on the B.O.D. of activated sludge effluent was noted during the coarse of some special experiments at the North Side plant of the Sanitary District of Chicago, but since the plan of operation did not include the production of nitrates, no study was made of the problem. In 1940 a similar condition was noted at the Southwest plant and, though it was of no particular interest from the standpoint of operation, a series of studies aimed at interpreting the high B.O.D. of nitrifying samples was initiated.

Exploratory Tests

Table I shows the results of a set of exploratory experiments in which settled sewage was used as the media. The purpose of these tests was to determine if pasteurization or acidification as a means of sterilization changed

TABLE I.—Exploratory B.O.D. Results on Treated and Untreated Settled Sewage

Test No.	Untreated (p.p.m.)	Acidified to pH 3.0–2.0 (p.p.m.)	Pasteurized (p.p.m.)	Acidified Sample Held 24 Hr. (p.p.m.)
1	32	32	52	28
2	45	49	39	37
3	58	56	54	58
4	100	98	100	93
5	83	84	70	83
6	118	121	109	114
7	84	84	84	84
8	235	225	235	215*
9	67	70	66	71**
Ave.	91	91	90	87

* Held 72 hr. ** Held 48 hr.

the values for the carbonaceous stage of B.O.D. The comparison between the B.O.D. obtained on the untreated samples and the acidified is in almost perfect agreement. The results for the pasteurized samples while somewhat more variable than the acidified are still in very close agreement with the untreated.

Table II shows the results of tests made simultaneously with those described above. For these tests reaerated activated sludge effluent was used. Again the two methods checked remarkably well with each other. Both are considerably lower than the untreated sample. While no determinations of nitrite or nitrate were obtained, the method of handling this effluent precluded any doubt that it was in the stage of active nitrification and that the high values obtained on the untreated samples are a result of this nitrification.

TABLE II.—Exploratory B.O.D. Results on Treated and Untreated Activated Sludge Plant Effluent (Reaerated)

Test No.	Untreated (p.p.m.)	Acidified to pH 3.0–2.0 (p.p.m.)	Pasteurized (p.p.m.)	Acidified Sample Held 24 Hr. (p.p.m.)
1	22.5	13.2	10.0	10.5
2	10.6	2.9	3.4	2.9
3	10.2	3.0	3.1	2.8
4	4.2	3.3	3.4	2.8
5	11.0	2.7	2.4	2.4
6	4.8	2.1	2.1	2.0
7	4.7	2.8	2.3	2.5
8	2.7	2.0	2.5	2.5*
9	8.8	2.4	2.4	3.2**
Ave.	8.8	3.8	3.5	3.4

* Held 72 hr. ** Held 48 hr.

Obviously, either pasteurization or acidification may be used to nullify the effect of nitrifying organisms in determining carbonaceous B.O.D. Acidification has the advantage of simplicity, and since results obtained in a similar manner on some industrial wastes have been accepted as representative, it also has the advantage of precedent. Furthermore acidification offers a method for preserving samples for B.O.D. determination more efficiently than by icing. The last columns of Tables I and II show results of samples that had been held 24 hours or more in this manner. They are for the most part within the limits of error of the method. They demonstrate the possibility of preserving samples by acidification *in the field* for determination of B.O.D.

Procedure for Determination of B.O.D. on Nitrifying Samples

Based on these two sets of exploratory tests the procedure adopted for further study of the effect of nitrification on B.O.D. follows: (1) acidification of the sample to pH 3.0 to 2.0; (2) reaction period not less than 15 minutes; (3) neutralization with alkali to pH 7.0 to 7.4; (4) dilution with standard dilution water seeded with settled sewage as provided in "Standard Methods."

TABLE III.—Comparison of B.O.D. Results on Raw Sewage

Test No.	5-Day B.O.D. (p.p.m.)		NH_3-N (p.p.m.)
	Standard Method	Modified Method	
1	160	132	6.0
2	128	153	8.0
3	195	225	8.0
4	163	155	7.5
5	175	213	8.0
6	90	95	9.5
7	88	110	10.0
8	133	133	8.0
9	293	300	32.0
10	220	215	8.5
11	168	148	8.5
12	70	80	8.0
13	285	268	9.0
14	290	305	8.0
15	178	170	8.0
16	75	100	9.0
17	208	220	10.0
18	170	150	7.5
19	172	140	9.0
Ave.	172	174	—

TABLE IV.—Comparison B.O.D. Results of on Nitrified Activated Sludge Effluent

Test No.	5-Day B.O.D. (p.p.m.)		NH_3-N	NO_2-N	NO_3-N
	Standard Method	Modified Method	(p.p.m.)	(p.p.m.)	(p.p.m.)
1	28.0	15.0	5.5	0.08	0.72
2	29.0	22.0	7.0	0.11	0.59
3	8.3	6.1	7.0	0.01	—
4	25.0	8.8	7.5	0.09	0.71
5	9.4	8.4	9.0	0.02	1.38
6	10.2	9.8	9.0	0.02	1.38
7	11.8	7.9	12.5	0.30	0.90
8	33.5	8.4	12.5	0.30	0.90
9	15.7	11.7	16.0	0.22	0.57
10	21.3	8.8	14.0	0.27	0.92
11	13.2	9.7	14.0	0.27	0.92
12	11.8	10.4	12.0	0.25	1.35
13	34.0	25.0	12.0	0.25	1.35
14	17.0	12.8	9.0	0.35	0.85
15	10.0	7.0	8.0	0.04	0.76
16	9.9	7.5	9.0	0.14	0.66
17	8.4	7.4	8.0	0.02	0.46
18	8.3	5.9	7.0	0.08	0.56
19	12.9	11.8	8.0	0 02	0.70
20	9.9	8.4	7.0	0.09	1.11
21	12.0	7.7	9.0	0.01	0.63
22	10.3	6.4	9.0	0.12	0.68
23	17.6	8.0	8.0	0.10	0.70
24	8.1	5.7	10.0	0.10	0.70
25	16.5	8.5	9.0	0.06	0.54
26	7.8	6.4	8.0	0.07	0.83
Ave.	15.2	10.4	9.6	0.18	0.77

Note: Results by modified method averaged 31.5 per cent lower than results by standard method.

Effect of Nitrification on Sewage and Activated Sludge Effluent

The experiments reported in Tables III and IV confirm the results found in the exploratory tests and establish more firmly the dependability of the method. For the tests of Table III raw sewage was used. The results obtained with the modified method vary in both directions from those found by use of the conventional B.O.D. procedure but are on the whole within the limits of error of the method. The averages for the series are practically identical. They indicate definitely that on sewages or wastes which do not ordinarily reach a condition of active nitrification during the 5-day incubation period, the modified method has little effect on the normal rate of B.O.D. for the first or carbonaceous stage.

In another series activated sludge effluent from the Southwest Works was used as the media for the comparison. The samples were taken daily and were in various stages of nitrification depending on plant operation. That they were all in the nitrifying stage is evident by the presence of nitrate and nitrite. The results show the effect of nitrifying flora on the B.O.D. In every case the B.O.D. determined by the conventional method was higher than that in which corrective measures were taken by acidification, neutralization and seeding to obtain normal carbonaceous B.O.D. The percentage differences vary from 3.9 to 75. Obviously those operators of activated sludge and trickling filter plants who attempt to obtain highly stabilized effluents are at a distinct disadvantage in evaluating the efficiencies of their plants unless measures to inhibit the effect of nitrifying organisms are taken.

Effect of Nitrification on Stream Conditions

In the studies of the effect of pollution and natural purification on the watercourse from Chicago to the mouth of the Illinois River, which studies have been carried on by the Sanitary District of Chicago for many years, values are obtained which indicate an increasing B.O.D. at downstream points. Interpretation of such values could easily lead to the belief that the river has deteriorated in its lower reaches. Such interpretation would be at variance with the known facts.

The results in Table V show this condition. The B.O.D. values obtained by the conventional method indicate improvement in the stream

TABLE V.—Comparison of B.O.D. Results on Illinois River Samples

Station	Miles	Number of Samples	5-Day B.O.D.		
			Conventional (p.p.m.)	Modified (p.p.m.)	Per Cent Difference
Summit	0	59	24.4	23.4	4.1
Lockport	20	65	18.8	16.7	11.2
Smith Bridge	35	40	7.8	6.8	12.8
Morris	50	150	5.4	4.1	24.1
Marseilles	66	75	3.7	2.3	37.8
Spring Valley	95	77	8.3	2.7	66.7
Henry	107	86	8.2	2.0	73.2
Lacon	124	72	7.4	2.3	68.9
Peoria	147	95	7.7	3.5	54.5

from a B.O.D. of 24.4 p.p.m. at Summit to 3.7 at Marseilles. Then, because of increased activity in the second stage B.O.D., there is a rise to 8.3 p.p.m. at Spring Valley and this condition is maintained through Peoria Lakes. When measures are taken to nullify the effect of active nitrification, however, the river shows improvement as far as Peoria Lake, the B.O.D. becoming progressively less from 23.4 p.p.m. at Summit to 2.3 at Lacon. In Peoria Lake there is a slight rise to 3.5 p.p.m. due to increased organic matter resulting from green growths and their products of metabolism.

The effect of nitrification on the stream is also demonstrated by the differences in B.O.D. values at the various stations expressed as per cent. These differences increase from practically nothing at Summit where there is no nitrification to 73.2 per cent at Henry where the intensity of nitrification is at its peak. The slight reductions in percentage at Lacon indicates the beginning of the effect of photosynthesis. At Peoria Lake where this effect is more intense the reduction is greater. The large increase between Smith Bridge and Morris is due to dilution by the Kankakee, and between Marseilles and Spring Valley the Fox River increases the dilution factor.

Table VI is given to show the increase in B.O.D. which would be possible if all the ammonia present were oxidized to nitrate. Computed from the NH_3-N content of the sample, values as high as 18 p.p.m. are possible. These values, however, are not attained by biological oxidation. The magnitude of such oxidation is indicated by the difference in B.O.D. determined by the conventional and modified methods.

TABLE VI.—B.O.D. and Related Data on Illinois River Samples

Item	Station			
	Spring Valley	Henry	Lacon	Peoria
Dissolved oxygen (p.p.m.)	7.8	6.7	6.1	9.7
D.O. saturation (%)	87	74	68	107
NH_3-N (p.p.m.)	3.9	3.4	3.4	1.3
Nitrogen as NO_2 and NO_3 (p.p.m.)	0.8	0.9	0.9	1.3
Conventional B.O.D. (p.p.m.):				
2-Day	2.4	1.9	1.9	2.7
3-Day	3.7	3.2	3.1	4.0
4-Day	5.7	5.6	4.9	5.6
5-Day	8.3	8.7	7.6	7.6
Modified B.O.D., 5-day (p.p.m.)	2.8	2.0	2.4	3.5
Nitrogenous B.O.D.—by difference (p.p.m.)	5.5	6.7	5.2	4.1
Theoretical max. nitrogenous B.O.D. (p.p.m.)*	17.8	15.6	15.6	5.9
River discharge (c.f.s.)†	5,400	—	—	7,300

* Computed as NH_3-N (p.p.m.) × 4.57. † Average discharge for same dates.

Conclusions

The studies and data reported here show that:

(1) Active nitrification adversely effects the B.O.D. values of activated sludge and trickling filter plants and of streams in a state of high stabilization. Such values may result in misinterpretation of the degree of treatment or of the stability of the water of a stream.

(2) Correction of these conditions is feasible by use of the modified method for determination of B.O.D.

(3) Either pasteurization and seeding or acidification, neutralization and seeding may be used to nullify the effect of nitrification in oxidized effluents and stream samples.

(4) Acidification has the advantage of simplicity of manipulation and precedent.

(5) Acidification can be used as a preservative for B.O.D. samples in the field.

Acknowledgment

Appreciation is due H. C. Kulisch for his work in making many of the B.O.D. determinations reported in this paper and to Dr. F. W. Mohlman for his advice and helpful suggestions in planning the experiments.

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FACTORS AFFECTING THE DIRECT OXYGEN UTILIZATION METHOD*

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The use of gaseous oxygen for the measurement of biochemical oxygen demand has been suggested by several authors. Sierp (1) developed an apparatus wherein sewage was maintained in contact with pure oxygen and its rate of absorption was measured in a calibrated eudiometer tube. The carbon dioxide liberated was absorbed from the oxygen by a caustic soda solution which was used to read the volume changes in the eudiometer. He found that the direct method gave somewhat higher results than did the widely used dilution method. Symons and Buswell (2), using apparatus similar to that developed by Sierp, also found that the method gave comparable results with the dilution method for sewage. It was also suggested that the method might be used for study of the biological oxidation of pure substances and trade wastes. Wooldridge and Standfast (3) investigated the use of the Barcroft differential manometer for the measurement of the oxygen demand of sewage. The results by that method were also higher than by the dilution B.O.D. technique. The differences were attributed to the maintenance of oxygen saturation, removal of carbon dioxide and sewage concentration.

The present work was undertaken to determine methods of procedure and factors affecting the use of the direct oxygen utilization method, particularly for strong industrial wastes. The results presented are illustrations to emphasize the importance of certain factors.

* Paper of the Journal Series, New Jersey Agricultural Experiment Station.

Apparatus

The apparatus used by Sierp and Symons was not fitted with all glass connections and therefore afforded possibilities of leaking should agitation be required. Attempts to use this type of apparatus in this work soon showed that all glass connections might be more suitable, especially if considerable agitation was necessary. Consequently an apparatus was designed possessing more desirable features.

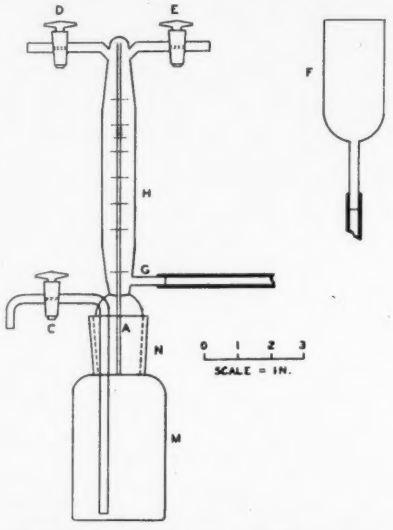

FIGURE 1.—Diagram of Sierp apparatus for the direct oxygen utilization method.

Figure 1 shows the apparatus, which consists of two parts. The lower chamber (*M*) holds the liquor under study. It is connected by means of a tapered glass connection (*N*) through which runs a diffusion tube (*A*) into

the gas chamber (*H*). This is calibrated in milliliters to 70 ml. Another tube (*C*) is used to remove excess liquid when oxygen is added to the apparatus. Two stopcocks (*D* and *E*) are used to add oxygen. The leveling funnel (*F*) is connected by a rubber tube to the buret at (*G*). All glass joints are lubricated with silicone stopcock grease. Figure 2 shows the apparatus assembled.

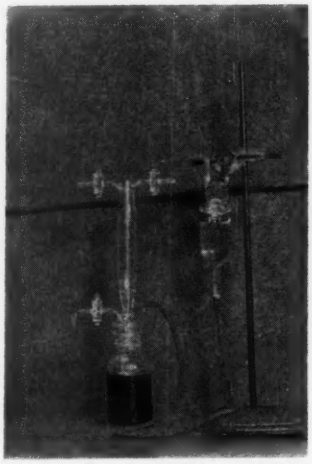

FIGURE 2.—Single Sierp apparatus.

Procedure

The bottle (*M*) is filled to a point about ⅛ in. above the bottom of its neck with the sample to be tested. With stopcocks (*D*) and (*E*) open and (*C*) closed, the upper part of the apparatus is pushed down into the neck of (*M*) so that no air is left in the bottle, and the diffusion tube (*A*) is filled. The upper part is then removed and the waste is measured in a graduate. This represents the total volume of the bottle (*M*) and should be marked on the bottle for future reference.

To use the apparatus, it is filled with waste at 20° C. With the leveling tube arranged so that the liquid level (10 per cent NaOH saturated with NaCl) is about ¼ in. below the top of the diffusion tube, the oxygen is passed through stopcock (*D*) to sweep out the air through (*E*). After about one minute, (*E*) is closed and (*C*) is opened. The oxygen displaces the liquid in the bottle through (*C*) into a graduated cylinder. This volume is designated *V* and may have to be increased for strong wastes. After about 100 ml. of liquid has been displaced, (*C*) is closed and the oxygen allowed to fill the buret (*H*); then stopcock (*D*) is closed.

The entire apparatus (except the leveling funnel) is shaken continuously by hand or machine for 5 minutes. Care must be exercised to maintain the temperature at 20° C.

The initial reading of the gas buret is then made together with temperature and atmospheric pressure readings. Subsequent readings of the apparatus can be made at intervals determined by the rate of absorption of oxygen and the needs of the experimenter. The frequency of shaking is important. For this work, a shelf was constructed which provided shaking (see Figure 3). A motor and a gear-reducing unit were mounted on a board base, which also held a shaft connected to an arm mounted off-center on the shaft. This arm was connected to a shelf held above the motor on hinges connected to the motor board base. The shelf was fitted with flat iron uprights with clamps to hold the apparatus. The arm was connected to the shaft so that the shelf could be shaken at horizontal displacements of ¼, ½, ¾, or 1 inch. The ¼-in. throw was found to give excellent shaking without too much jar on the glass apparatus. The motor was connected to the shaft by an adjustable pully. The speed was such that the shelf was displaced back and forth 250 times a minute. The motor was connected to an automatic (Tork) timer so that the shelf was shaken 10 minutes and rested 10 minutes. The entire apparatus was kept in a room with a constant temperature at 20 ± 0.5° C.

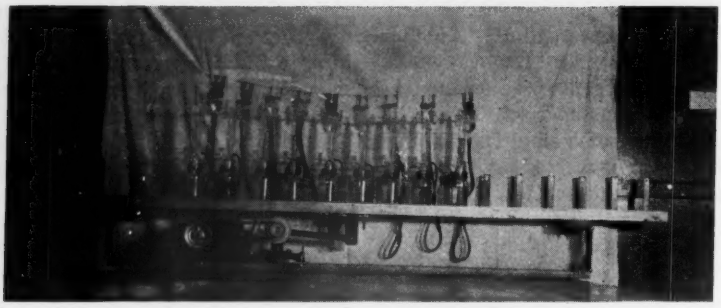

FIGURE 3.—Shaking shelf assembly.

Initial Reading

When the initial reading is taken, two requirements must be satisfied. The temperature of the apparatus must be 20° ± 0.5° C. The waste must be saturated, or nearly so, with oxygen. If this latter condition is not attained, subsequent readings will represent not only the rate of oxygen utilization, but also oxygen solution.

Experiments were performed to measure the rate of oxygen solution in sewage and slaughterhouse waste under an atmosphere of pure oxygen and with 200 ml. of liquid in the apparatus. Under quiescent conditions, the rate of solution during the first hour was 3.0 p.p.m. of oxygen for the sewage and 2.6 p.p.m. for the slaughterhouse waste. Thus to attain saturation under quiescent conditions, hours would be required. Similar experiments were conducted in which the apparatus was continuously shaken by machine. It was found that both wastes reached a fairly constant value of 35 p.p.m. dissolved oxygen at the end of 5 minutes. Shaking by hand for 5 minutes gave similar results, showing that if the temperature of the apparatus is 20°C., the initial reading of the buret can be made after 5 minutes of shaking.

The frequency and the duration of shaking are important, particularly when stronger wastes are studied. For sewage studies, shaking for 5 minutes once or twice a day is considered to be satisfactory. When using strong wastes the rate of solution of oxygen may be so slow in comparison to the utilization rate that more frequent shakings may be necessary. The practice of shaking 10 minutes and resting 10 minutes was adopted by this laboratory, since a great variety of wastes were being studied at the same time.

Carbon Dioxide Correction and Calculations

In a biological oxidation involving carbonaceous material, one volume of oxygen will produce one volume of carbon dioxide. As originally designed, all carbon dioxide liberated into the oxygen atmosphere above the liquid was supposed to diffuse rapidly through the diffusion tube into the gas buret and be absorbed by the alkali. Analyses of the gas in the bottle at varying stages of oxidation of sewage and slaughterhouse waste indicated that such was not the case. The percentage of carbon dioxide varied considerably, from 1 to 2 per cent to almost 40 per cent of the gas in the lower chamber, depending upon the waste and the stage of oxidation. The decrease in volume of the gas in the buret would not, therefore, represent all of the oxygen utilized by the waste, but would be low by a volume equal to that of the unabsorbed carbon dioxide. To correct for this undesirable feature, experiments were performed to cor-

relate the carbon dioxide content of the gas with some easily determined quantity. Apparatus containing varying quantities of sewage, slaughterhouse waste and sulfite liquor was devised for this purpose. The decrease in volume of gas was measured over varying intervals of time and then the gas in the apparatus was analyzed for carbon dioxide. This latter analysis entailed displacing the gas in the apparatus through stopcock (*E*) into barium hydroxide with water through stopcock (*C*). The barium carbonate was then separated and washed by centrifuging and titrated with standard 0.1 N HCL and NaOH to the methyl orange endpoint. Table I shows some data obtained on the relationship of unabsorbed carbon dioxide, the rate of gas utilization and liquor volume. In Figure 4 is plotted the percentage by volume of carbon dioxide in the lower chamber (*K*) against the total decrease in volume in the buret (*J*) divided by time (*t*) in days. It is assumed that the carbon dioxide in the upper chamber is removed in a few minutes as a result of its proximity to the moving sodium hydroxide surface. This was borne out experimentally. For simplification of calculations, the CO_2 in that chamber is considered to be zero. The dimensions of the apparatus were uniform enough to make results comparable.

TABLE I.—Results on Rate of Gas Utilization in Comparison with Carbon Dioxide Absorption

Waste	*t* (days)	*J*/*t* (ml./day)	*K* (% CO_2)	Waste Volume (ml.)
Sewage	2	9.7	3.0	100
Sewage	2	20.0	6.2	200
Sewage	9	8.7	6.8	200
Sewage	7	4.2	2.6	200
Sewage	7	4.7	2.8	200
Sewage	9	4.8	3.0	100
Slaughterhouse	1	3.8	1.7	100
Slaughterhouse	1	10.2	3.5	200
Slaughterhouse	1	11.2	1.7	200
Slaughterhouse	2	6.5	3.3	100
Slaughterhouse	2	11.0	3.9	200
Slaughterhouse	3	23.8	11.8	200
Slaughterhouse	3	8.1	5.0	100
Slaughterhouse	3	12.3	9.0	200
Slaughterhouse	4	13.3	11.0	200
Slaughterhouse	6	5.0	5.5	100
Slaughterhouse	6	9.2	10.4	200
Slaughterhouse	7	13.0	13.5	200
Slaughterhouse	8	3.6	5.2	100
Sulfite liquor	2	112	27.8	50
Sulfite liquor	2	73	24.5	80
Sulfite liquor	2	104	37.5	100

The symbols used in calculations are defined as follows:

J = Total decrease in volume of gas in the buret from the initial reading to time t, corrected for temperature and pressure.

K = Percentage by volume of CO_2 in gas in lower chamber (M).

V = Volume of gas in lower chamber and equals the liquid removed from bottle (M) in filling the apparatus with oxygen.

L = Volume of waste in the lower chamber and is equal to the volume of bottle (M) minus V.

O = Actual volume of oxygen utilized by waste at 29.9 inches of mercury and 20° C.

P = Atmospheric pressure in inches of mercury.

R_o = Initial buret reading uncorrected for T and P.

R_t = Buret reading at time t, uncorrected for T and P.

T = Temperature in degrees absolute.

t = Time in days.

In order to determine the oxygen utilized by a waste in terms of parts per million of B.O.D. it is necessary to calculate the value of O. If all carbon dioxide were immediately removed, then $O = J$. This, however, was found to be experimentally incorrect. Therefore, the volume of carbon dioxide in the lower chamber must be added to J to obtain O. Thus:

$$O = J + \frac{KV}{100} \qquad (1)$$

The value J is calculated by subtracting the buret reading after time

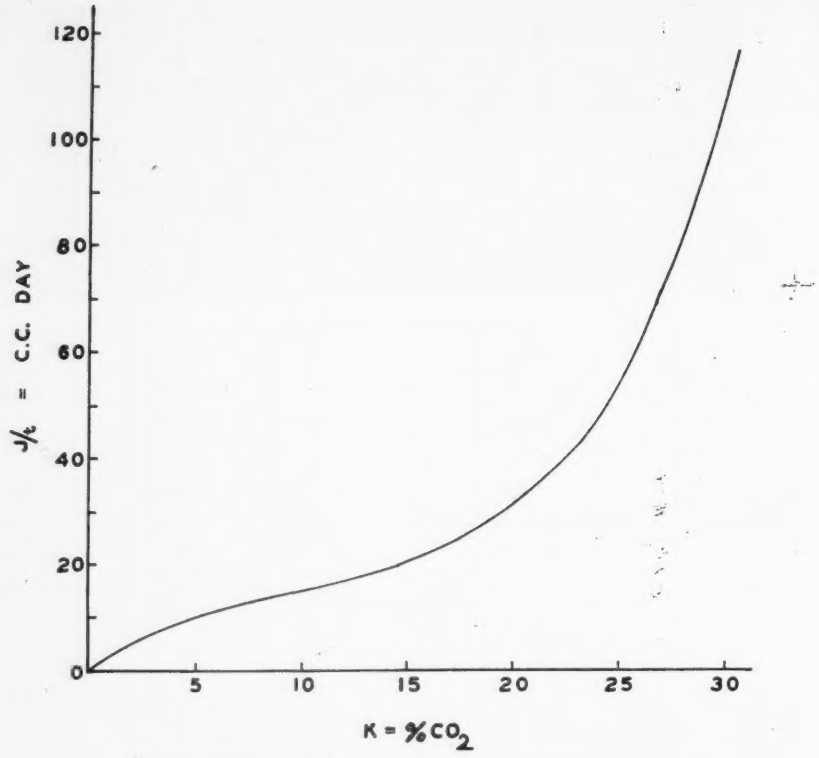

FIGURE 4.—Carbon dioxide correction curve.

t from the initial buret reading. This is calculated as follows:

$$J = \left[(R_0 + V)\frac{P_0}{29.9}\frac{273}{T_0} - V\right] - \left[(R_t + V)\frac{P_t}{29.9}\frac{273}{T_t} - V\right] \quad (2)$$

If T does not vary more than 0.5° C. from 20° C., the error involved in omitting the temperature correction is about 0.3 per cent. Therefore, a simplification of the equation for J was used.

$$J = \left[(R_0 + V)\frac{P_0}{29.9} - V\right] - \left[(R_t + V)\frac{P_t}{29.9} - V\right] \quad (3)$$

The variation in P may be larger and cannot be controlled. Therefore, correction for P was considered necessary.

The value K can be determined from Figure 2 by entering J/t. V is known by measurement. Therefore, O in ml. of oxygen at standard pressure and at 20° C. can be calculated.

To convert O to parts per million of B.O.D., the following is used:

$$\text{B.O.D. (p.p.m.)} = O\frac{1000}{L}1.33 = 1330\frac{O}{L} \quad (4)$$

The constant 1.33 is the weight in milligrams of 1 ml. of oxygen at standard pressure and 20° C.

TABLE II.—Oxygen Demand of Sewage by the Direct and Dilution Methods

Time (days)	Unseeded		Unseeded		Soil Seed (1 per cent)		Dilution Method
	Corrected[1]	Uncorrected[1]	Corrected[1]	Uncorrected[1]	Corrected[1]	Uncorrected[1]	
1	69	48	78	53	71	49	57
2	96	80	99	82	89	74	95
3	113	100	120	105	106	94	—
4	129	117	133	120	118	107	118
5	136	126	140	130	125	116	130
6	138	129	142	134	128	120	138

[1] For CO_2.

Duplication of Results and Effect of Seeding

Experiments were carried out to compare duplicate results and the effects of seeding on the B.O.D. of a sewage and a slaughterhouse waste. To illustrate the effect the results for two sets of unseeded sewage and sewage seeded with 1 per cent of a soil suspension are shown in Table II. Results of using the dilution method are also shown, together with the corrected and uncorrected results for CO_2.

The method generally agrees within itself by 5 per cent. It is also apparent that the CO_2 correction for sewage would not be absolutely necessary after the second day, since the accuracy is not greatly increased. Seeding is also unnecessary in experiments with sewage.

Table III shows some results obtained with slaughterhouse waste unseeded and seeded with 1 per cent each of sewage, soil suspension, and an adapted seed prepared by aerating slaughterhouse waste. The data show results corrected and uncorrected for CO_2 and also the results obtained by the usual dilution method.

The unseeded sewage and the soil-seeded wastes agree well within themselves, whereas the adapted seed gives lower results. Agreement with the dilution method is also about 5 per cent after the carbon dioxide correction is made. These results indicate that seeding of this type of waste is not important, but correction for carbon dioxide is very important.

A short 3-day series was run on sulfite liquor. This contained about 8 to 10 per cent total solids. Mineral salts were added to make up the deficiency of nitrogen, phosphorus, and potassium. Table IV shows the results with no seed and 1 per cent soil, sewage, and adapted seed. Comparison was made with the dilution method.

TABLE III.—Oxygen Demand of Slaughterhouse Waste by the Direct and Dilution Methods

Time (days)	Unseeded		Sewage Seed (1 per cent)		Adapted Seed (1 per cent)		Soil Seed (1 per cent)		Dilution Method
	Corrected[1]	Uncorrected[1]	Corrected[1]	Uncorrected[1]	Corrected[1]	Uncorrected[1]	Corrected[1]	Uncorrected[1]	
1	414	265	403	257	400	254	351	216	370
2	532	401	529	400	515	387	508	382	510
3	603	486	599	484	583	470	605	499	610
4	655	553	642	542	619	522	657	556	670
5	702	611	696	606	658	574	695	605	710
6	730	655	728	655	697	625	707	635	740

[1] For CO_2.

TABLE IV.—Oxygen Demand of Sulfite Liquor by the Direct and Dilution Methods

Time (days)	Unseeded		Sewage Seed (1 per cent)		Adapted Seed (1 per cent)		Soil Seed (1 per cent)		Dilution Method
	Corrected[1]	Uncorrected[1]	Corrected[1]	Uncorrected[1]	Corrected[1]	Uncorrected[1]	Corrected[1]	Uncorrected[1]	
1	970	350	890	330	1,960	810	830	310	4,400
2	710	440	690	420	4,900	3,370	580	370	13,000
3	1,000	690	1,000	700	6,200	4,650	730	530	17,000

[1] For CO_2.

The results are of interest since the direct method gave low and variable results as compared with the dilution method. Even when the correction for CO_2 was made, the results were still not comparable. This could have been due to insufficient carbon dioxide correction, but even this would not explain such large discrepancies. A more reasonable explanation is the relationship of concentration of retarding, inhibitory or toxic materials to the activity of the organisms. In the dilution method, the solids concentration is of the order of 0.1 per cent or less; in the direct method, the order is about 10 per cent. Thus the presence of any toxic substances in the sulfite liquor would be 100-fold or more times as concentrated.

Incomplete and slow absorption of carbon dioxide by the NaOH necessitates the use of a correction factor. The curve developed need not be used for ordinary sewage, but it should be used for stronger wastes.

Because of concentration effects, certain very strong wastes, such as sulfite liquor, might be expected to give low results for B.O.D. as compared with the dilution method.

Seeding may prove to be important, particularly to organic wastes of a special nature, such as sulfite liquor. Addition of nutrient salts may also prove necessary where these are lacking.

The direct oxygen utilization method has been shown to give results comparable to the dilution method for several wastes. The method may have limited application for routine determinations of sewage, but it can be used more readily than the dilution method to determine such effects as concentration and toxicity of certain substances on the biochemical oxygen demand of industrial wastes. It is useful for measuring the oxygen demand of suspended material, since shaking of the apparatus is possible. It is expected that many uses can be made of the apparatus in studies of strong industrial waste where the dilution method may prove inadequate or unreliable.

Conclusions and Summary

The apparatus described in this report can be used for the determination of the biochemical oxygen demand of sewage or industrial wastes. Certain rules of procedure are necessary for the correct functioning of the apparatus. Temperature variations should be kept at a minimum. The apparatus should be shaken for at least 5 minutes before the initial reading is made to insure saturation of the waste with oxygen.

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Industrial Wastes

THE TREATMENT OF CYANIDE WASTES BY CHLORINATION *

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Free cyanide is one of the most toxic components of industrial wastes that are often discharged into sewers and streams. Because its toxicity to fish varies with pH, concentrations of other ions present, temperatures and oxygen content of the receiving water—as well as activity, stage of development and species of fauna (1) in the stream—it is difficult to set up exact limits of concentration which can be safely discharged. Table I indicates the general range of tolerable concentrations. Under some conditions, as little as 0.1 p.p.m. has proved fatal to fish (4). From 0.1 to 0.3 grams of CN are fatal to humans (5).

When received in sewage treatment plants, cyanide not only interferes with both aerobic and anaerobic processes (43) but if the sewage is chlorinated, extremely noxious gases may be produced.

For 35 years or more various investigators (14) have sought a satisfactory method of treating cyanide wastes. Among the methods that have been used are acidification and removal of the resulting HCN gas by air blowing (6) (7) (8) (9), reaction with "lime sulfur" (10) (11) (12), aeration (13), treatment with ferrous sulfate (14) (15), and oxidation with potassium permanganate (16).

Acidification is commonly practiced in the gold mining industry for the recovery of cyanide from gold refining solutions (17) (18).

All of the above methods have been used commercially for the reduction of the cyanide content of concentrated solutions, but they all leave a substantial cyanide residual. This residual may be serious unless extremely large dilutions are available. Another objection to all of these methods is that the pollution load is increased by the addition of objectionable chemicals (12). None of these treatment methods are applicable to the treatment of dilute wash solutions such as are obtained from plating operations. Chlorination of solutions at pH above 8.5 has now proven to be an economical and satisfactory method for treatment.

The development of the treatment of cyanide wastes by chlorination has been slow and many have contributed. Early theoretical discussions (6) and early experimental work indicated that the chlorination of a cyanide waste would increase its toxicity by the presence of dissolved cyanogen chloride. Unfortunately, these experiments were carried out under acid conditions, and the true reactions under alkaline conditions were not discovered. Helmut Beier discovered in Germany that the chlorination of a cyanide solution under alkaline conditions would yield cyanates, and he has obtained a German patent (19) using the reaction as a means of waste disposal. A similar patent application in this country (20), vested in the Alien Property Custodian, has since been abandoned (21).

The first published records of a successful elimination of cyanide from

* Presented at the 22nd Annual Conference of the Michigan Sewage Works Association; Jackson, Michigan; May 16, 1947.

TABLE I.—Toxicity of Cyanide Compounds

Chemical Formula and Reference*	Name	Concentration as CN (p.p.m.)	Effect	Fish
NaCN (1)	Sodium cyanide	10	Kills in 4 min.	Shiner
NaCN (1)	Sodium cyanide	5	Kills in 12 min.	Shiner
NaCN (1)	Sodium cyanide	2	Kills in 17 min.	Shiner
NaCN (3)	Sodium cyanide	1	100% mortality in 20 min.	Trout
NaCN (2)	Sodium cyanide	0.8	100% mortality in 24 hr.	Adult minnows 4″–6″ catfish 12″–15″ carp
NaCN (2)	Sodium cyanide	0.5–0.7	25% mortality in 24 hr.	Adult minnows 4″–6″ catfish 12″–15″ carp
NaCN (2)	Sodium cyanide	0.4	Destroyed bal. in 1 hr.	Adult minnows 4″–6″ catfish 12″–15″ carp
NaCN (2)	Sodium cyanide	0.3	No effect in 24 hr.	Adult minnows 4″–6″ catfish 12″–15″ carp
NaCN (3)	Sodium cyanide	0.050	100% mortality in 120 hr.	Trout
NaCN (3)	Sodium cyanide	0.020	No effect	Trout fingerling
KCNO (2)	Potassium cyanate	264	No effect in 24 hr.	Adult minnows

*See bibliography.

industrial wastes using chlorine was published in Russia in 1941 (22) and in Germany in 1942 (23). At about the same time, Albright and Friel (24) designed and built the first commercial plant in this country using chlorination. A second plant was built by the Talon Company at Meadville, Pennsylvania, with Prof. George E. Barnes acting as consultant. Three other plants are in the process of either erection or initial operation, and several others have been designed.

Sources of Cyanide Waste

While cyanide compounds are widely used in industry, five processes are responsible for most of the cyanide wastes causing serious stream pollution and presenting problems in sewage plant operation. The processes are: (1) the plating of metal parts, (2) the case-hardening of steel, (3) the neutralizing of acid "pickle scum," (4) the refining of gold and silver ores, (5) the scrubbing of gases from blast and producer gas furnaces. Each of these processes may have a multiplicity of variations both in design of equipment and method of operation. For this reason, it is imperative that the particular plant in question be carefully studied before the design of waste treatment facilities is begun.

Accurate estimates or measurements must always be made of the flow and

of the rate of change of the flow, the concentration and rate of change of concentration of cyanide, as well as the details concerning other wastes that must be treated.

Metal Plating

The wastes from a typical plating operation consist of dilute solutions of the various plating baths. The concentration of each constituent will vary with the "drag-out" (the amount of solution carried out with the metal being plated or "work") and with the volume of rinse water being used. The drag-out will vary with the speed that the work is transferred from one bath to another, and with the size and shape of the work. Naturally, irregular and cup-shaped pieces carry more solution to the rinse water than do flat surfaces.

The first step in plating consists of removing heavy scales and other oxide coatings and adherent oil and grease. The scale on steel is usually removed either by an acid pickle consisting of sulfuric or nitric acid, or a mixture of the two, or by the sodium hydride process. A dichromate pickle, consisting of a mixture of sulfuric acid and sodium dichromate, is often used on brass and nickel steel parts.

If grease or cutting oil is on the work, solvent degreasing or alkaline electric cleaners are used. Solvent degreasing does not ordinarily create a waste problem. The alkaline cleaners consist of a mixture of several compounds including sodium hydroxide, sodium carbonate, silicates, and phosphates.

In waste treatment plant design the acids should, if possible, be segregated and neutralized separately. The rinse waters from the alkaline cleaners and from the sodium hydride process should be mixed with the cyanide waste.

The work is carried from the cleaning process to a cyanide rinse which consists of a high concentration sodium or potassium cyanide bath, to a strike solution containing high "free" cyanide and low metal content where the first adherent coat of metal is deposited, and then to the plating solution itself. The rinse and strike solutions are not ordinarily followed by running water rinses and therefore present no pollution problem. The plating solutions vary widely, depending upon the ideas of the plating supervisor and upon the type of work. Brass, copper, cadmium, gold, silver, and zinc are the metals commonly plated from cyanide solutions. The formulae for typical cyanide plating solutions are given below (25):

Brass Plating

Copper cyanide	4 oz./gal.	30,000 p.p.m.
Zinc cyanide	1¼ oz./gal.	9,200 p.p.m.
Sodium cyanide	7½ oz./gal.	57,000 p.p.m.
Sodium carbonate	4 oz./gal.	30,000 p.p.m.
	Total CN = 39,000 p.p.m.	

Cadmium Plating

Cadmium oxide	3.5 oz./gal.	27,000 p.p.m.
Sodium cyanide	14.5 oz./gal.	113,000 p.p.m.
	Total CN = 60,000 p.p.m.	

Copper Plating

Copper cyanide	3.0 oz./gal.	23,000 p.p.m.
Sodium cyanide	4.5 oz./gal.	35,000 p.p.m.
Sodium carbonate	2.0 oz./gal.	15,500 p.p.m.
	Total CN = 23,600 p.p.m.	

Silver Plating

Silver cyanide	4 oz. av./gal.	30,000 p.p.m.
Potassium cyanide	5.5 oz. av./gal.	42,000 p.p.m.
Potassium carbonate	6.0 oz. av./gal.	47,000 p.p.m.

Total CN = 28,300 p.p.m.

Zinc Plating

Zinc cyanide	8 oz./gal.	62,000 p.p.m.
Sodium cyanide	3 oz./gal.	23,000 p.p.m.
Caustic soda	7 oz./gal.	54,000 p.p.m.

Total CN = 37,500 p.p.m.

It will be noted that, except for variation in concentrations of alkali and "free" cyanide (sodium or potassium), the various metal baths are similar in composition.

In making up the plating solution, however, the comparatively simple formula for the solution becomes quite complex due to the ionization of the various constituents and the reactions between them. For instance, a zinc plating bath would contain the following: $Na_2Zn(CN)_2$, $Na_2Zn(CN)_4$, NaOH, NaCN, Na_2CO_3, Na_2ZnO_2, Na^+, Zn^{++}, $Zn(CN)_4^{--}$, ZnO_2^{--}, CN^-.

In addition to the drag-out, the baths themselves are occasionally dumped and fresh solutions made up. The writer has found a wide variation in practice in this respect. Many industries interested in fine finishes dump their plating solutions once a week, while others claim that they dump only once in twenty years.

In all cases, some provision should be made in the treatment plant to handle the concentrated dump solution so as to prevent the sudden influx of high concentration cyanides. Means of proportioning the concentrated waste into the main flow is commonly provided.

In addition to the cyanide wastes outlined above, wastes from other plating operations will often be present. Hexavalent chromium from chrome plating, anodizing of aluminum, and dichromate pickle are the most common. If treatment of chrome waste is required, it can be carried out with ferrous sulfate, iron turnings, or sulfur dioxide, either as a separate process or as a treatment subsequent to cyanide treatment.

Nitriding of Steel

The process of heat treating steel parts by cyanide consists of immersing the part at a predetermined temperature in a molten bath of a mixture of sodium cyanide, barium chloride, sodium chloride, potassium chloride, and strontium carbonate. After the part which is to be hardened has been placed in the molten bath for the proper period, the work is removed and quenched in either oil or water. Water quenching in a continuous flow of water is the more common practice. The waste problem naturally arises from the overflow of water which carries with it the sodium cyanide which has been dragged from the molten bath, some sodium carbonate which has been formed by the breakdown of sodium cyanide, and some iron complexes. The discharge from a bath of this nature may be expected to run as high as 50 to 100 p.p.m. of free cyanide.

The heat treatment also involves a problem in the disposal of spent salt baths. It has been common practice to remove these salts and bury them in nearby dumps. The practice should be discouraged, since cases are on record (27) which indicate that such dumps are eventually leached out and either kill fish in nearby streams or endanger public water supplies obtained from streams or nearby wells.

Cyanide Neutralization

In the pickling of steel sheet for the removal of mill scale, the metal is usually dipped in dilute sulfuric and hydrochloric acid. As the steel leaves such a pickle bath, a pickle smut, consisting of materials not soluble in the acid, such as iron carbide, silicon, silicon carbide, copper and copper sulfides, remains on the surface (28). In addition, ferrous sulfate and ferrous chloride are formed and cling to the surface. If the sheet is then air dried or neutralized with caustic, the ferrous iron is converted to ferric which covers the pickle smut and forms a coating which is quite difficult to remove. This objectionable coating accelerates rusting, makes for poor adhesion of paint and plating, accelerates the formation of dross in galvanizing and generally spoils the finish of the sheet. This objectionable coat can be removed by agitating the pickled sheet in a solution containing 0.2 oz. per gal. of sodium cyanide and 0.2 oz. per gal. of sodium hydroxide.

The following reactions, yielding entirely soluble compounds, take place (28):

$$6NaCN + FeSO_4 \rightarrow Na_4Fe(CN)_6 + Na_2SO_4$$

$$6NaCN + MnSO_4 \rightarrow Na_4Mn(CN)_6 + Na_2SO_4$$

$$6NaCN + Cu_2SO_4 \rightarrow 2Na_2Cu(CN)_3 + Na_2SO_4$$

The waste from such a process consists of the wash waters (usually warm) that will carry an appreciable concentration of all these products together with the drag-out of the original solution plus the dump solution itself. Unlike usual plating procedure, the neutralizing solutions are dumped frequently in order to maintain quality work. It is not unusual for plants to dump their cyanide neutralizing baths once a day. The resulting mixture of wash and dump solutions usually varies between 200 and 1,000 p.p.m. of CN.

Cyaniding of Gold and Silver Ores

In the cyaniding of gold and silver ores, cyanide is discharged with the spent treating solution, after acid treatment by various modifications of the Halverson Process, and is contained in the sand and slime as it is discharged to the dumps. The first source produces daily quantities sufficient to cause fish killings (3) while the latter source is likely to cause problems only after heavy rains (5).

Chemistry of the Treatment

When chlorine is added to a free cyanide solution with sufficient free alkali present to maintain a pH above 8.5, the cyanide is oxidized to cyanate:

$$NaCN + 2NaOH + Cl_2 \rightarrow NaCNO + 2NaCl + H_2O$$

This reaction is practically instantaneous. Under all conditions which we have tested, it is complete in less than one minute.

Theoretically, it requires 2.73 parts of chlorine per part of CN and 3.08 parts of caustic per part of CN. However, most trade wastes contain a substantial portion of the required free alkali.

If an excess of chlorine is added, free chlorine residual, as measured by by the O-T-A test (44), will be found in the solution after one or two minutes.

In all trade wastes and laboratory samples that we have tested, no cyanide within the limits of titration accuracy has been found in the presence of free available chlorine at pH 8.5.

The oxidation of free cyanide by chlorine has been checked in the laboratory. To a known potassium cyanide solution, having a concentration of about 50 p.p.m. CN, a boric acid-sodium hydroxide buffer was added to hold the pH at 8.5. When a quantity of chlorine is added which is substantially less than the theoretical amount required to oxidize all the cyanide to cyanates, the reaction occurs almost

quantitatively. For instance, in a KCN solution containing 50 p.p.m. CN, when enough chlorine is added theoretically to convert 58 per cent of the cyanide to cyanate, 58 per cent of the cyanide disappears, 49 per cent of the cyanide appearing as cyanate. However, as more chlorine is added to such a solution, particularly beyond the theoretical 2.73:1 ratio, the cyanate which is formed is again oxidized:

$$2NaCNO + 4NaOH + 3Cl_2 \rightarrow 2CO_2 + 6NaCl + N_2 + 2H_2O$$

To carry out this second oxidation, it requires 4.09 parts of chlorine per part of CN and 3.08 parts of NaOH, or the total oxidation of the cyanide to carbon dioxide and nitrogen requires 6.82 parts of chlorine and 6.16 parts of NaOH per part of CN.

This second reaction occurs much more slowly. In order to reach completion, excess chlorine must be added. For potassium cyanide solution of 50 p.p.m. initial CN concentration in a boric acid-sodium hydroxide buffer, the rate and completeness of the reaction are shown on Figure 1.

It will be noted that 7.35 parts of chlorine per part of CN were required as compared with the theoretical 6.82. It is believed that most of this additional chlorine is used to oxidize the nitrogen to nitrous oxide or perhaps higher oxides of nitrogen.

If the pH of the solution is permitted to drop very much below 8.5, nitrogen trichloride is also formed.

While the cyanide oxidation has been shown in two steps, it can readily be carried out in a single contact tank if sufficient chlorine is added initially.

The oxidation of cyanide to cyanates by chlorination is exothermic. A 1,000 p.p.m. CN solution, as potassium cyanide, will undergo a temperature rise of 7.16° F. when chlorinated, assuming no heat dissipation. Naturally, other concentrations will have *proportionate* raises. This is important only in cases of the higher cyanide concentrations.

For instance, in concentrations such that the final temperature of the solution exceeds 120° F., a substantial portion of the chlorine added will react to form chlorates, and only a small percentage of the chlorine will react with the cyanide present. It should be noted, however, that if chlorine is added slowly enough to allow the solution to remain cool, or if the solution is cooled or diluted to reduce the final temperature below the critical, high concentrations can be treated.

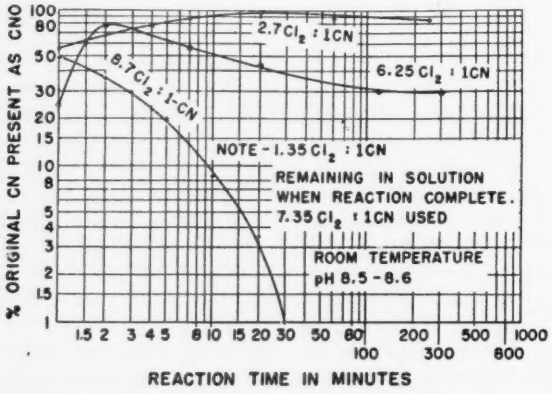

FIGURE 1.—Oxidation of cyanide in KCN solution containing 50 p.p.m. initial CN concentration by dosages of chlorine.

The significance of these reactions from the viewpoint of stream pollution can be seen by reference to Table I. It will be noted that the cyanates have a toxicity to fish of approximately one-thousandth that of cyanides. Naturally, in designing a treatment plant, each problem will have to be considered on the basis of local conditions. It would seem reasonable to suppose, however, that the oxidation of cyanides to cyanates will be sufficient except in cases where practically no dilution is present or in cases where a large number of plants are discharging cyanide to the same watershed.

The hydrolysis of cyanate to ammonia and carbon dioxide under acid conditions is a familiar reaction. In very acid streams, this reaction may be of importance in the elimination of cyanate radical. However, the velocity of the reaction at near neutral pH values is not known.

Similarly, under alkaline conditions, oxidation of the cyanate by the dissolved oxygen in the stream may occur, but it is believed that the reaction takes place too slowly to be of practical importance. In any case, few plant effluents, even without further dilution, will contain high enough cyanate concentrations to affect stream life.

While the details of the reaction between free cyanide and chlorine, which are presented here, are indicative of reactions that occur in actual composite wastes, tests should always be made on the actual waste before conclusions regarding quantities of chlorine required and rates of reactions are reached. Some wastes have required as much as 4 parts of chlorine per part of CN to obtain a free chlorine residual at the end of one minute.

Actual tests on the effect of treated concentrated wastes on fish life are being published in a companion paper.

The cyanide radical will seriously impair both aerobic and anaerobic sewage treatment processes (43). The nature of these effects by chlorinated concentrated waste is being studied by Dr. G. M. Ridenour.

It should be noted in both of these studies that the treated wastes used were concentrated solutions equivalent to dumped plating solutions, and that the treatment was carried out so as to oxidize only a portion of the cyanate.

It should also be noted that these experiments, particularly those involving acidified sludge, were complicated by the presence of dissolved metals and that most of the tests were run without pH adjustment, which could easily be done in an operating plant.

Present State Regulations

A judge once said, "We have been meticulous in avoiding the statement of an exact definition of fraud lest the scheming mind of man devise a fraud that is without our definition." Similarly, the various state authorities have avoided setting up an exact definition of the requirements on cyanide wastes lest variations of toxicity with temperature, dissolved oxygen, or other pollution factors make the specified limits dangerous to fish life. As in all stream pollution problems, there is always the question of whether a stream is not already so grossly polluted as to make a regulation impractical. Naturally, as the streams gradually improve in condition, regulations will have to be made more stringent.

In a recent survey, 31 states replied to a questionnaire regarding the limits of cyanide concentrations permitted in a stream in their state. Eighteen states indicated that they would regulate the concentration of cyanide discharged.

Typical remarks included: "On streams we have insisted that not over a trace of cyanide, as CN, be present in the waste . . ." (30).

States which have no specific regulations remark that they "recognize the danger . . . of cyanide pollution"(31). Others will permit "no industrial

waste which may cause objectionable changes in the quality . . ." of any potable supply (32).

In a mining state where the cyaniding of gold is a common practice, "We attempt to prevent any cyanide from reaching the stream, since we believe that if any does reach the stream, there may be times when the amount would be greater than allowable" (33).

The industrial states are still more stringent. For instance, "In general, we would require that the maximum concentration of the cyanide radical in the receiving water course would be less than 0.1 p.p.m. In addition, we would also be concerned about the concentrations of any metals usually associated with electro-plating waste, such as copper, nickel, cadmium, chromium, etc." (34), or ". . . the requirements which govern in respect to the discharge of cyanide and its compounds necessitate complete removal of oils, greases, acids, alkalies, and toxic, putrescible, taste and odor producing, and other substances inimical to the public interest in the receiving stream" (35).

The thought that is being given to the problem is evidenced by the remarks of J. L. Hedgepeth, "We have set no standards in Virginia for any such discharges and hope that it will not be necessary to establish such generally applicable regulations. At the present time, our thinking is along the lines of complete elimination of cyanide content from industrial waters . . ." (36).

In commenting on potable water sheds, Dr. J. Lynn Mahaffey has said, "This department recently rendered an opinion in the matter of plating establishments desiring to establish on potable water sheds, in which the department refused to grant a permit to an industry to discharge wastes containing cyanides into any portion of a potable water shed, including the subsoil, since a dangerous precedent would be established and if extended to other applicants would be very difficult to properly police and supervise and a hazard to the safeness of the (public potable water) supply will result" (37).

Plant Design

The design of a treatment plant for the elimination of cyanide waste by chlorination will vary widely, depending on a large number of factors. As has already been pointed out, the factors of the operation of the industrial plants which control the concentration of cyanide present in the waste and the rate of change of concentration, as well as the quantity and rate of change of quantity of the total waste and the amount of other polluting factors present, will have a large bearing on the final design. The amount of dilution and the quality of the water in the receiving stream will also have a major effect on the design of the plant, particularly with respect to the amount of oxidation that will be required of the cyanide and the amount of metals which must be removed.

Because of the natural high chlorine demand and natural high buffer capacity of domestic sewage, treatment of cyanide wastes can almost always be carried out more economically at the industrial plant than at a sewage treatment plant.

Batch Treatment

The simplest type of treatment plant which is applicable to the small industrial establishment is illustrated on Figure 2. Here the concentrated and dilute cyanide solutions, which have been kept free from acid content by collection in separate sewers, are carried to a central mixing tank which is provided with an agitator. After the waste liquor has been fed into the storage tank, the pH of the waste can be raised, if necessary, by the addition of sufficient lime directly into the tank or by the gradual addition of caustic as the solution is pumped from the

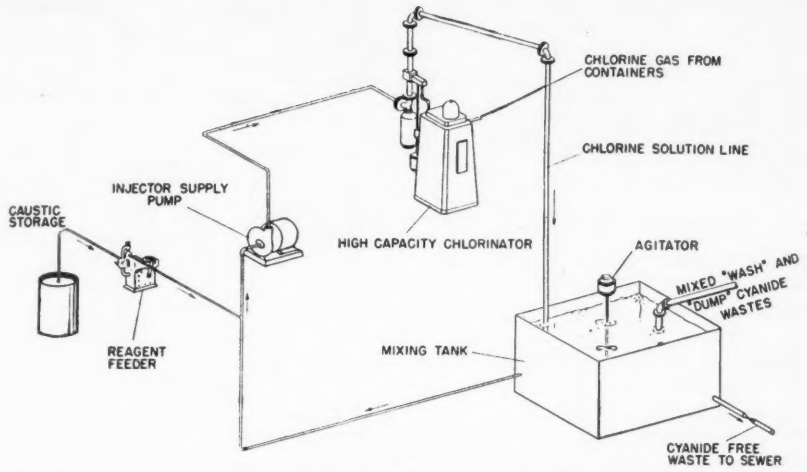

FIGURE 2.—Diagram illustrating batch treatment of cyanide wastes by chlorination.

tank. After the waste has been thoroughly mixed and the pH adjusted, it is then pumped from the tank through the injector of the chlorinator, where a controlled and measured amount of chlorine is added, and returned to the storage tank. To avoid objectionable fumes, the pH of the waste must be carefully controlled, and the dissolving and mixing of the chlorine and waste must be rapid and complete. Local acidification must be carefully avoided.

Prof. George E. Barnes has already described the plant of the Talon Company at Meadville, Pa., which is designed in accordance with these general principles (45).

Continuous Treatment

When the quantities of waste being discharged by an industrial plant are so large as to make retention tanks too big for economical construction, continuous treatment with automatic controls is indicated. Figure 3 illustrates schematically this type of plant. Assuming the waste is from a plating operation, the wash water from alkaline and electrolytic cleaners, from cyanide rinses, and from plating rinses, is carried continuously to the treatment plant. Concentrated cyanide waste, including a dump solution of cyanide rinse and dump plating bath solutions, is carried in a separate sewer into a storage tank and proportioned into the general waste system by a reagent pump.

The addition of chemicals to this solution can either be carried out in a flume, as indicated in the drawing, or in a pipe line, whichever seems most economical. The alkali—either sodium hydroxide, hydrated lime, or soda ash—is added at a rate sufficient to hold the pH at the required value. The choice between hydrated lime and sodium hydroxide is a matter of balancing the lower cost of the lime against the ease of feeding of the liquid caustic. Another factor to be considered is the production of sludge when lime is used.

In the larger plants the use of automatic dry feed equipment for feeding the lime can be justified. If caustic is used, a proportioning valve or a reagent feeder should be used. In either case, the rate of addition of the caustic should be controlled by a glass electrode located beyond the point

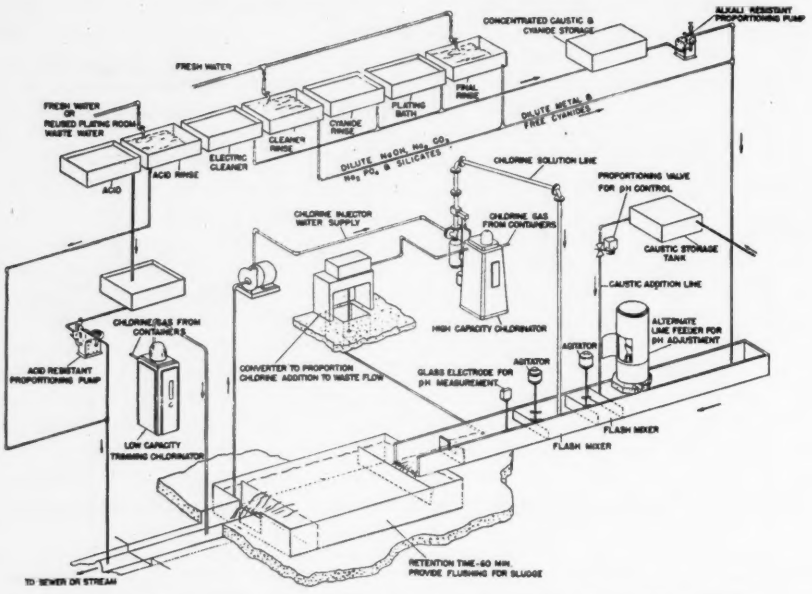

FIGURE 3.—Diagram illustrating continuous treatment of cyanide wastes by chlorination.

of chlorination. Chlorine should be added, using pumped plant effluent for the operation of the chlorine injector. If there are wide variations in the rate of flow, an automatic chlorinator should be used.

A reaction tank or a series of reaction tanks should be provided if it is necessary to oxidize the cyanide to carbon dioxide rather than to the cyanate. They are also advisable safety features if substantial variations in the cyanide content is expected.

A plant, substantially as shown in Figure 3, has been built and is in operation. It was designed for an average flow of 400 g.p.m. with a concentration of 100 p.p.m. CN. Operation to date has yielded a cyanide free discharge.

Similar principles were involved in the first cyanide treatment plant using chlorine in the United States. This plant was designed by Albright & Friel, Inc., of Philadelphia in cooperation with Metcalf and Eddy of Boston, Mass. It was erected in 1942 at Johnsville, Pa., and is now known as the U. S. Naval Air Modification Unit. The wastes, which average 50,000 g.p.d., originate in metal plating and finishing operations including anodizing. The plant has already been described (24). It is substantially as shown in Figure 4.

Mr. R. A. Morrissey, sanitary engineer at the U. S. Naval Air Modification Unit, has been kind enough to furnish the following analysis. The untreated waste characteristics are as follows:

	Average	Maximum	Minimum
pH	7.7	10.5	2.5
Chromium (p.p.m.)	100.0	2,500.0	70.0
Cyanide (p.p.m.)	2.0	40.0	1.0
Cadium (p.p.m.)	10.0	60.0	3.0
Copper (p.p.m.)	3.0	40.0	1.0

The treated waste, as discharged to the river, showed as follows:

	Average	Maximum	Minimum
pH	9.6	11.5	8.5
Free residual chlorine	0.6	1.0	0.3

Chromium, cyanide, cadmium, and copper in the treated waste were all below titratable limits. The treated waste is discharged into a tributary of a stream used as a public water supply and no complaints have been received from farmers, land owners, or the water company.

Recovery Possibilities

In the case of a large majority of the plants, the amount of metal in the waste is not sufficient to warrant the cost of recovery. Similarly, the total amount of cyanide present in the waste is uninteresting from a recovery viewpoint.

One factor of recovery which should not be overlooked in the design of a plant is the reuse of the water itself. The effluents from such a plant are usable as rough rinse water in a number of processes and can also be used as cooling water for many operations around an industrial plant. In those areas where water is a scarce commodity, the factor of reusing the effluent from such a treatment plant should be given serious consideration.

Analytical Methods

The accurate determination of cyanide in dilute water solutions is a difficult procedure. In clear solutions of sodium and potassium cyanide, the prussian blue method, the ferric thiocyanate method, the phenolphthalin method, and the Liebig titration with silver nitrate are all possible.

If it is desired to titrate total cyanides including metal complexes and thiocyanates, distillation prior to titration is necessary. Distillation is also necessary where chrome or other ions cause a color in the waste.

In the Liebig titration, the end point itself is very difficult to recognize, and several trial runs should be made be-

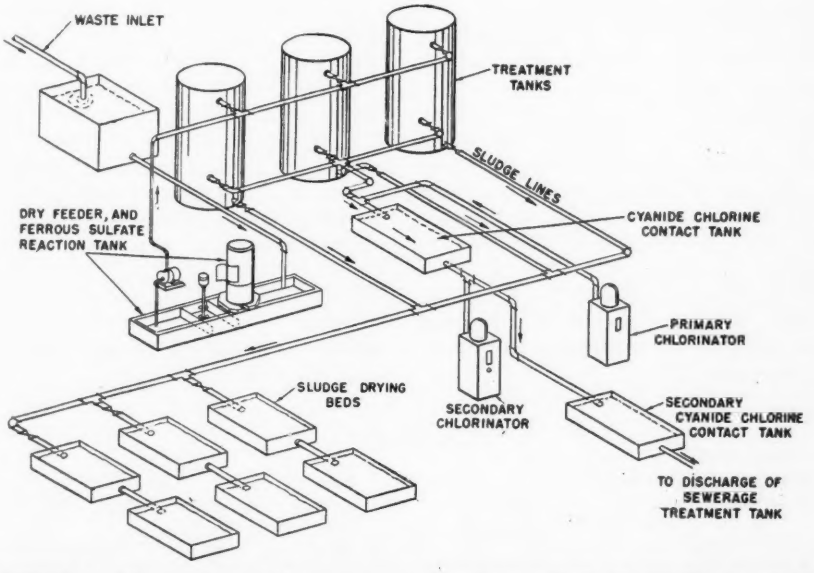

FIGURE 4.—Diagram of cyanide waste treatment plant at U. S. Air Modification Unit, Johnsville, Pa.

fore actual titration is begun. The end point of the titration is a slight yellow opalescence which gradually develops with time. For this reason, when dealing with very low concentrations, it is advisable to run a blank sample at the same time as the unknown titration is being made. In this way, the end point of the unknown and the blank can be directly compared.

The Liebig method leaves much to be desired with respect to accuracy at lower concentrations. Below 0.1 p.p.m. it is almost useless. Several newer methods (39, 41, 42, 44) have been suggested, but we have not yet had experience enough to be able to recommend any of them.

As has already been pointed out, we have never yet found a case where free chlorine residual, as measured by the ortho-tolidine-arsenite test (44), has been present in the same sample in which free cyanide has been found. From our experience, we believe that the presence of the free available chlorine residual is a comprehensive and accurate test for the freedom from cyanide in a solution. A check for pH should be made on each sample. Before this test is used in any commercial application, however, complete Liebig titrations for cyanide on samples which have been found to contain a free chlorine residual should be made.

Fasken (40) reviewed some of the methods and recommended the use of the ferric thiocyanate method for concentrations above 0.1 p.p.m. and the phenolphthalin method below 0.1 p.p.m. (44). When total cyanide complexes are desired, the distillation procedure is necessary.

Conclusion

The application of chlorine for the oxidation of the highly toxic cyanide radical to form cyanates or carbon dioxide and various oxides of nitrogen is now a proven process, having been verified by extensive laboratory tests and several plant installations over a period of years. The overall method is competitive in cost with any other method that has been previously suggested for the disposal of cyanide, and has the advantages of being cleaner, easier to operate, and of producing an effluent which is vastly superior.

Acknowledgment

The preparation of this paper has only been made possible by the splendid cooperation of a large number of interested parties. The writer cannot possibly acknowledge the source of all the information contained in the article. A number of the ideas have originated in conferences with various engineers who have been faced with the problem of design in cyanide waste treatment plants.

Particular appreciation, however, must be expressed to Mr. Francis Friel and Mr. Gordon Weist, of Albright & Friel, for their assistance in obtaining the Brewster results; to Prof. George E. Barnes of Case Institute of Technology, and Mr. Manley Ross of E. I. DuPont de Nemours and Company, Inc., for their many helpful suggestions; to Dr. Harry C. Marks, Mr. A. E. Griffin, Mr. N. S. Chamberlin, and Mr. Paul E. Sharts of Wallace & Tiernan Co., Inc., for their painstaking review of the manuscript and many constructive criticisms.

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CHARACTERISTICS OF STRAWBOARD WASTE

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The problem of strawboard disposal has harassed strawboard manufacturers as well as public health authorities for many years. The last extensive study of this problem was the work recorded by Hommon in 1918 (1). Until recently, little additional study has been made of strawboard waste.

In an attempt to decrease the pollution of streams caused by this waste, the National Council for Stream Improvement (of the Pulp, Paper and Paperboard Industries), Inc. (NCSI), an organization representing about eighty per cent of the pulp, paper, and paperboard manufacturers in the United States, established a research project at Purdue University on August 1, 1945. The purpose of this project was to study the characteristics of strawboard waste, to investigate methods of treatment, and, if possible, to develop means of recovering and profitably utilizing the material in the waste.

The first year of study at Purdue was devoted to investigation of the characteristics of strawboard waste. Some of the more important results of these studies will be presented in this paper.

The Strawboard Mill

Plant Layout and Operation

In many respects the manufacturing process and the equipment used in making strawboard remain the same as they were when R. L. Sackett described a typical strawboard mill in 1905 (2). Equipment used includes the rotaries, for cooking the straw; beaters, for washing and pulping the cooked straw; Jordans, for further refining the pulp; and the paper machines, for making strawboard from the pulp. A flow diagram, tracing the course of both product and waste from an average mill, is shown in Figure 1.

The rotaries in which the straw is cooked are spherical in shape and are equipped for slow-speed rotation during the period of cooking. These rotaries are about 14 ft. in diameter, with a capacity of from 3½ to 6½ tons of straw per rotary. Uncut and undusted straw is placed in the rotaries, and water and chemicals are added. The straw is cooked with steam under a pressure of 30 to 50 p.s.i. for periods ranging from 3 to 10 hours. Generally, about 1 lb. of water is used for every 2½ lbs. of straw. For many years, lime was the only chemical used in the cooking process. The trend has been toward the addition of small amounts of caustic or soda ash, which considerably reduces the amount of lime required. In present practice, lime is used in amounts varying from 60 to 230 lbs. per ton of straw. The amount of caustic soda used is generally under 30 lbs. per ton of straw. Other chemicals sometimes used in small quantities are sulfur and sodium sulfite.

The two functions of the beater are washing and beating. The period of time required for this operation is generally from 2 to 4 hours. Beating is an essential part of the process since it has considerable effect on the character of the pulp leaving the beaters.

From the beaters, the pulp passes through the Jordans and finally arrives at the "wet end" of the paper machines. Water is removed from the pulp by filtration, and the pulp discharged onto felts. The pulp at this point contains about one-third water.

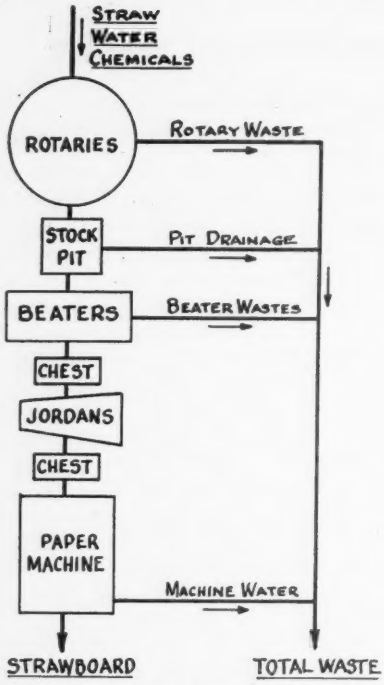

FIGURE 1.—Flow diagram of a typical strawboard mill.

Once on the felts, the pulp is transported through the "hot rolls," finally emerging as strawboard.

The final product is a coarse, brown paper which finds its chief use as corrugating material and wrapping paper.

Sources of Waste Waters

Generally speaking, strawboard mill waste (total waste) is a combination of wastes from the following four sources:

1. Rotaries (Rotary Waste).
2. Stock Pit (Pit Drainage).
3. Beaters (Beater Wastes).
4. Paper Machines (Machine Water).

The wastes from the beaters and paper machines are considered to be the major components of the total waste.

In some mills beater wastes may be obtained from two sources. This situation occurs when the beating process is divided into two stages, sometimes called washing and breaking (or beating). The units themselves are called washer-beaters and breaker-beaters. In this paper, the terms "primary" and "secondary" beater will be used to designate the first and second steps in the process, regardless of whether the first step is a beating or a washing process. Where the process is accomplished in one step, the unit will be designated as a washer-breaker-beater.

Volumes of Waste Water

From the flow data obtained from mill operators as well as a study of the reports by Hommon (1) and the U. S. Public Health Service (3), it is estimated that volumes of total waste may be expected to average around 30,000 gal. per ton of finished product. This figure is subject to considerable variation.

The volumes of waste waters from the rotaries and the stock pit are very small in comparison to the volumes of waste contributed by the beaters and paper machines.

Beater wastes usually contribute from one-third to one-half of the total waste volume. Under existing variations in the re-use and recirculation of machine water as practiced by the industry, it is difficult to make a general statement regarding the machine wastes. Where only small volumes of machine water are recirculated, machine water discharges may amount to 15,000 to 20,000 gal. per ton of finished product.

Analysis of Wastes

Solids and B.O.D.

Samples of strawboard wastes were obtained during an inspection trip of eight strawboard mills in the Midwest. These samples were analyzed for B.O.D. as well as total solids, total volatile solids, suspended solids, and suspended volatile solids. Results of tests on some of the more important of these wastes are recorded in Table I.

TABLE I.—Results of Analyses of Strawboard Wastes

Sample	No. of Samples Averaged	Total Solids (p.p.m.)	Total Vol. Solids (p.p.m.)	Total Vol. Sol. (%)	Susp. Sol. (p.p.m.)	Susp. Vol. Sol. (p.p.m.)	Susp. Vol. Sol. (%)	5-Day 20° B.O.D. (p.p.m.)
Total waste	5	3,835	2,611	68	1,707	1,230	72	847
Machine water	5	2,729	1,963	72	931	748	80	314[1]
Primary beater	2	17,847	12,353	69	5,100	3,470	68	—
Secondary beater	3	7,095	4,932	69	2,951	2,183	74	1,665[2]
Washer-breaker-beater	1[3]	15,900	11,320	71	7,460	4,910	66	—

[1] Average of two tests. [2] Result of one test. [3] Results of test by Mr. James Hargleroad.

The B.O.D. values for total waste, from which the average results in Table I were obtained, ranged from 525 p.p.m. to 980 p.p.m. Machine water B.O.D. varied from a low of 198 p.p.m. to a high of 430 p.p.m. Tests on total beater wastes indicated B.O.D. values as high as 3,800 p.p.m.

Chemical Analysis of Dried Solids

The results of the nitrogen, phosphoric acid, and potash analyses of strawboard waste (Table II) were studied with considerable interest, since it has been reported, and generally accepted, that a satisfactory balance of these materials must be present to facilitate the complete and rapid biologic decomposition of wastes.

In order to determine whether sufficient nitrogen, phosphoric acid, and potash (N-P-K) are present in total strawboard waste, it was necessary to take into account the oxygen used by the waste during the decomposition of its organic matter (*i.e.*, B.O.D.) In order to do this, the N, P, and K content of the waste was divided by the B.O.D. of the waste, resulting in the term p.p.m. N, P, or K per p.p.m. B.O.D. of the waste.

With the above information it was possible to compare the N-P-K content of strawboard waste with the N-P-K requirements of biological organisms as shown in tests by Lea and Nichols (4).

It was observed in these tests that during the 5-day oxidation period of the B.O.D. test, certain quantities of nitrogen and phosphoric acid were utilized by the organisms in the B.O.D. bottles. Using the data presented by Lea and Nichols, it was possible to calculate the amount of nitrogen and phosphoric acid required per part per million of oxygen utilized in the B.O.D. test.

The following table, Table III, shows the results of the N-P-K studies on strawboard waste as compared with the quantities of these materials utilized in the Lea-Nichols test.

The data presented in the foregoing table indicate that the nitrogen content of strawboard waste is lower than

TABLE II.—Chemical Analysis of Strawboard Waste (In Per Cent of Dried Total Solids)

Sample	Total Nitrogen (N)	Total Phosphoric Acid (P_2O_5)	Total Potash (K_2O)	Ether Soluble Extracts
1. Total waste (Ave. of 4 samples)	1.08	0.43	1.03	1.23
2. Machine water (Ave. of 2 samples)	1.04	0.15	—	—
3. Primary-beater (Washer)	1.48	0.41	0.19	0.80
4. Primary-beater (Breaker)	0.89	0.44	0.14	0.65
5. Secondary-beater (Washer)	1.03	0.50	—	—
6. Rotary waste	0.62	0.17	0.47	0.04

TABLE III.—N-P-K Content of Strawboard Waste as Compared to N-P-K Utilization in Oxidation Tests

	P.P.M. of Chemical per P.P.M. of Oxygen Used in 5-Day Oxidation	
	Lea-Nichols Tests	Strawboard Waste
Nitrogen (N)	0.0966–0.168	0.0411–0.0457
Phosphoric acid (P_2O_5)	0.0069–0.0102	0.0146–0.0241
Potash (K_2O)	0.0093–0.0137[1]	0.0273–0.0814

[1] Based on potash present in Lea-Nichols dilution water rather than on amount utilized.

the optimum suggested by the work of Lea and Nichols for satisfactory biological oxidation.

Concentrations of phosphoric acid and potash in the total strawboard waste compare favorably with the amounts of these chemicals used in the Lea-Nichols tests.

Chemical Analysis of Ashed Solids

Samples of waste from a number of mills were analyzed for silica, iron and aluminum, calcium, magnesium, sodium, potassium, and sulfates.

From the viewpoint of basic research, the chemical analysis of strawboard waste is of considerable importance. Since few, if any, chemical analyses of this waste have ever been made before, it is felt that the results shown in Table IV will be of value in future studies on the disposal of these wastes.

These tests showed that silica, calcium, and sodium make up a large percentage (over 60 per cent by weight of ash) of the inorganic solids.

The high silica content of the straw used in the process, along with the relatively large amounts of dirt, weeds, etc. carried into the process with the straw, suggests that these materials are the source of the silica found in total waste.

An analysis of the product during the stages of its manufacture made it possible to trace the high calcium content of the waste waters back to the chemicals used in the cooking process. It is believed that the high sodium content of the waste water may be traced back to the same sources.

The comparatively high magnesium content of samples 4 and 5, Table IV, was due to the high dolomitic lime used in the mill from which these samples were obtained.

Physical Characteristics of Suspended Solids in Total Strawboard Waste

Effects of Size of Suspended Solids Particles on Solids Determinations

Early in this study, it was observed that there were large discrepancies between the percentage of suspended solids removed at the Terre Haute pilot plant. (a project originally conducted by the Terre Haute Paper Company,

TABLE IV.—Chemical Analysis of Strawboard Waste Total Solids, Ashed (In Per Cent of Ash)

Sample	Silica (SiO_2)	Iron and Aluminum ($Fe_2O_3+Al_2O_3$)	Calcium (Ca)	Magnesium (Mg)	Sodium (NaCl)	Potassium (KCl)	Sulfates (SO_4)
1. Total waste (Ave. of 4 samples)	20.71	6.56	27.39	3.53	12.32	4.86	7.95
2. Machine water (Ave. of 2 samples)	24.04	11.51	21.54	2.57	—	—	10.26
3. Primary beater (Washer)	14.77	7.95	23.10	1.50	12.30	1.91	13.46
4. Primary beater (Breaker)	9.36	5.29	24.63	12.99	13.91	0.88	2.60
5. Secondary washer-beater (Washer)	12.07	10.31	24.62	11.49	—	—	5.72
6. Rotary waste	2.66	2.22	26.28	6.07	14.13	7.02	4.95

and later incorporated as a joint project of the NCSI and the Terre Haute Paper Company), and the removals obtained in laboratory settling tests. This difference led to an investigation which resulted in establishing the fact that many of the so-called suspended solids removed by Gooch crucibles are not removed by coarser filter papers.

In order to investigate the magnitude of the differences in results occurring from variations in methods of testing for suspended solids, the following experiment was made:

Two 1,000-ml. samples of strawboard waste were allowed to settle in cylinders for a period of 30 minutes. At the conclusion of the settling period, five 100-ml. portions were drawn from the top of each cylinder.

Suspended solids tests were run on one set of these samples by the standard "Gooch" method. The second set of samples was filtered through 9-cm. Buchner funnels fitted with No. 4 Whatman filter paper discs, that being the procedure that had been used in determining suspended solids at the Terre Haute pilot plant.

The curve in Figure 2 was plotted from the results obtained in the laboratory experiment. This curve shows the relations between the "Gooch" and "No. 4 Whatman" suspended solids determinations on identical samples of strawboard waste. Since the data covered only a range between 1,870 p.p.m. (Gooch) and 1,086 p.p.m. (Gooch) suspended solids, the straight line portions of the curves were extended.

On the basis of the foregoing work, it is evident that the "No. 4 Whatman" method is certainly not equivalent to the "Gooch" method of running suspended solids for strawboard

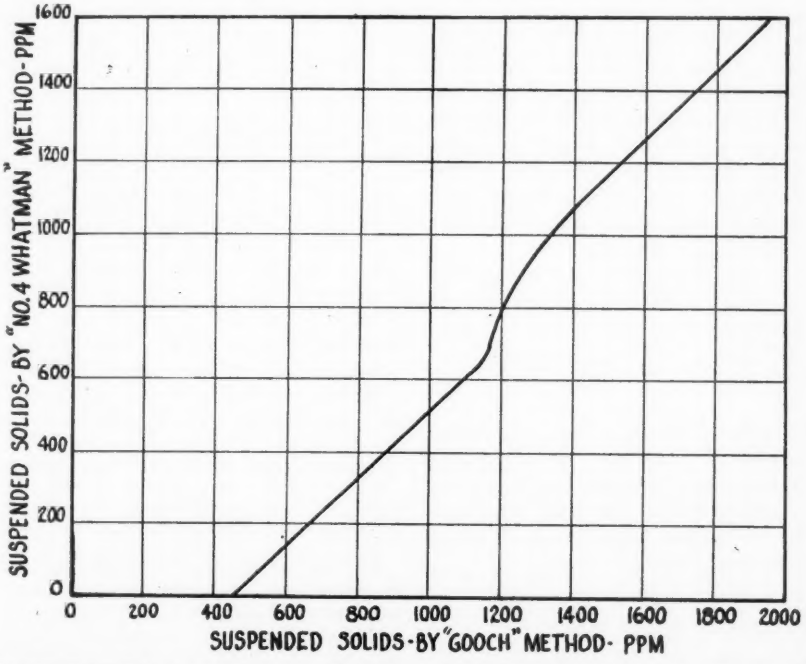

FIGURE 2.—Relationship between "Gooch" and "No. 4 Whatman" methods of suspended solids determination.

waste. The following example should serve to emphasize this statement.

Example: The following results were obtained from settling tests on a total strawboard waste sample, using the "No. 4 Whatman" method for suspended solids determinations.

Initial suspended solids	769 p.p.m.
Susp. solids—60 min. settling	51 p.p.m.
Suspended solids removed by settling	718 p.p.m.

$\frac{718}{769} \times 100 = 93.5\%$ removal of suspended solids (as recorded by "No. 4 Whatman")

The same analysis made by the "Gooch" method gave the following results (on the basis of the test results shown in Figure 2).

Initial suspended solids	1170 p.p.m.
Susp. solids—60 min. settling	548 p.p.m.
Suspended solids removed by settling	622 p.p.m.

$\frac{622}{1170} \times 100 = 53.2\%$ removal of suspended solids (as recorded by "Gooch")

This study of variations in methods of running suspended solids determinations on strawboard waste indicates that considerable differences in values may result from variations in test methods because of the size of the suspended solids particles.

It is interesting to note that the differences in results are less pronounced at the higher concentrations of suspended solids, no doubt because of the early deposition of a filter mat on the paper.

In spite of the fact that only small quantities of strawboard waste can be filtered through a Gooch crucible, it is felt advisable to use the standard method of suspended solids determination on these wastes.

Sedimentation and Concentration of Strawboard Waste Solids

To observe the effect of settling on the removal of suspended solids from strawboard waste, a series of settling tests were run. Samples (1,000-ml.) of total strawboard waste were allowed to settle for one hour. At the end of the period of settling, the volume occupied by the settled solids was recorded, and a suspended solids determination made on the liquor drawn from the surface of the settled sample.

Results of these tests, including the concentration of the settled solids, are shown in Table V.

TABLE V.—Suspended Solids Removal and Sludge Concentration of Strawboard Waste (Sixty-Minute Sedimentation Period)[1]

Date 1946	Suspended Solids		Removal of Suspended Solids (%)	Concentration of Settled Solids	
	0 Min. (p.p.m.)	60 Min. (p.p.m.)		Ml./ Liter	Per Cent
Sept. 20	1644	768	53.3	45	2.02
Oct. 4	1830	910	50.4	40	2.39
Oct. 10	1750	640	62.8	45	2.62
Oct. 19	1708	760	55.4	37	2.64
Oct. 24	1852	716	61.3	42	2.78

[1] These tests were made by Mr. James Hargleroad.

Additional laboratory tests made on the settling characteristics of strawboard waste indicated that increased removals of suspended solids could be expected when the temperature of the waste was increased. By raising the temperature of the waste from 25° C. to 44° C., removals of suspended solids were increased by 15 per cent. Neither pre-stirring nor increasing the concentration of the suspended solids had any effect on the rate of settling.

Oxygen Requirements of Strawboard Waste

Relation of Solids to B.O.D.

The use of consecutively finer filter mediums on a sample of strawboard waste offered an excellent opportunity to study the effect of these various filter mediums on the removal of suspended solids, and also to study the

effect of suspended solids removal on the B.O.D. of strawboard waste.

The test was made using a 1,000-ml. sample of total strawboard waste. This sample was settled for 30 minutes and the top 900 ml. passed through five consecutively finer filter mediums, the final filtration being made through a parchment disc.

The results of this test are shown in Table VI.

In a sample on which the B.O.D. was found to be only 570 p.p.m. for the unfiltered, unsettled waste, removal of all the suspended material (including colloidal material that passed through the asbestos mat but not through the parchment filter) resulted in a removal of 52.6 per cent of the B.O.D. In other words, it was found that 47.4 per cent of the B.O.D. of a strawboard waste sample was in the dissolved state.

Rates of Biological Oxidation of Strawboard Waste

In considering the treatment of any waste by biological means, two major characteristics of the material must be determined: (1) the N-P-K content, and (2) the availability of the organic material present in the waste.

In order to determine the availability of the organic matter in strawboard waste, a "characteristic B.O.D. curve" was produced. This test consisted of setting up a B.O.D. series on a sample of waste and making daily B.O.D. determinations on these samples through the first stage of oxidation.

So that the effect of the N-P-K content of the strawboard waste might not be a factor in the test, Lea-Nichols dilution water, containing the essential mineral salts required for satisfactory biological oxidation, was used to make up the B.O.D. samples.

The tests were made on samples of settled strawboard waste. These tests were run in two series, the first (Series A) beginning one day after the samples were collected, and the second (Series B), two days after that. Series A ran for only 8 days; Series B for 20 days.

The results of the tests, Series A and B, are shown in Table VII. Figure 3 compares the characteristic B.O.D. curve of the settled strawboard waste with the characteristic B.O.D. curve of sewage (after Theriault).

From Figure 3 it may be observed that the characteristic B.O.D. curve of strawboard waste closely follows the theoretical first-stage B.O.D. curve of sewage. The sharp break between the sixteenth and eighteenth days indicates

TABLE VI.—Comparison of Filtrates of Strawboard Waste Passed Through Various Filter Mediums

	Total Solids and Total Volatile Solids				5-Day B.O.D.	
	Total Solids (p.p.m.)	Total Vol. Solids (p.p.m.)	Per Cent Removal		P.P.M.	B.O.D. in Sample (%)
			Total Solids	Total Vol. Solids		
Sample 1—Total waste, unsettled	3463	2408	—	—	570	—
Sample 2—Supernatant from total waste, settled 30 min.	3151	2175	9.0	9.7	580	100
Sample 3—Filtrate through No. 4 Whatman	2479	1704	28.4	29.2	410	71.9
Sample 4—Filtrate through No. 30 Whatman	2449	1688	29.2	29.8	430	75.4
Sample 5—Filtrate through No. 42 Whatman	2460	1676	29.2	30.4	370	64.9
Sample 6—Filtrate through asbestos mat	2237	1517	35.4	37.0	380	66.7
Sample 7—Filtrate through parchment disk	2080	1240	39.9	48.5	270	47.4

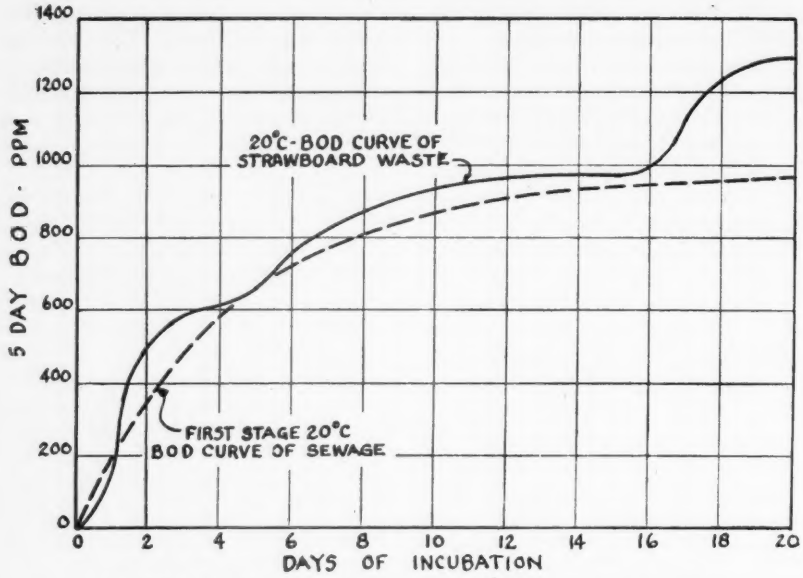

FIGURE 3.—Characteristic B.O.D. curve for strawboard waste.

that nitrification begins during this period.

It may be concluded from this test that the organic material found in strawboard waste can be oxidized biologically at a rate almost identical to the biological oxidation rate of sewage.

The Decrease on B.O.D. of Strawboard Waste on Standing

Some interesting results were obtained from the incubation of undiluted strawboard waste samples. The first of these tests showed 80 per cent

TABLE VII.—Results of Characteristic B.O.D. Curve Tests on Settled Strawboard Waste

Days	Series A				Series B			
	Dilution (%)	20° C. B.O.D. (p.p.m.)			Dilution (%)	20° C. B.O.D. (p.p.m.)		
		Test 1	Test 2	Ave.		Test 1	Test 2	Ave.
1	1.5	113	—	113	1.0	165	165	165
2	1.5	500	500	500	1.0	500	510	515
3	0.5	560	560	560	(1.0) (0.4)	615	562	586
4	0.5	560	560	560	0.4	600	—	600
5	0.5	580	591	586	0.4	650	675	663
6	0.5	670	760	715	0.4	850	700	775
7	0.5	680	—	680	—	—	—	—
8	0.5	800	—	800	0.4	863	875	869
10	—	—	—	—	0.4	788	912	850
12	—	—	—	—	0.2	1100	800	950
14	—	—	—	—	0.2	1100	900	1000
16	—	—	—	—	0.2	825	1025	925
18	—	—	—	—	0.2	1325	1175	1250
20	—	—	—	—	0.2	1200	1350	1275

reduction of B.O.D. in samples incubated at 37° C. for 14 days, and 95 per cent reduction of B.O.D. in samples incubated for 21 days. This test was made by filling 4-oz. bottles with strawboard waste, stoppering the bottles with cotton plugs, and incubating at 37° C.

The result of the foregoing test was in sharp contrast to another test conducted at room temperature in a gallon bottle. Results of this latter test showed no reduction in B.O.D. after a period of 24 days' incubation at room temperature.

Decrease in B.O.D. of Sewage-Strawboard Waste Mixtures

In order to determine the effect of sewage on the reduction of strawboard waste B.O.D., incubation tests were run on samples of strawboard waste diluted with sewage.

The tests were made on settled strawboard waste samples containing about 10 per cent less B.O.D. and about 40 per cent less suspended solids than the original total strawboard waste sample.

Two series of tests were made. In Series A, three sets of 4-oz. bottles were filled to the neck, the bottles plugged with cotton, and placed in the 37° C. incubator. One set of these bottles contained 100 per cent strawboard waste, one set contained 100 per cent sewage, and one set contained a 50–50 mixture of sewage and waste. One bottle from each of the three sets was removed from the incubator every second day and B.O.D. tests made on the contents of each bottle.

Results of Test Series A are shown in Table VIII. These results are expressed graphically in Figure 4.

A study of Figure 4 suggests that the rate of B.O.D. reduction of mixtures of sewage and strawboard waste is much more rapid than the rate of B.O.D. reduction of either of the component parts of the mixture.

The fact that the zero-day B.O.D. of the strawboard waste sample was almost the same as the zero-day B.O.D. of the 50–50 mixture of sewage and strawboard waste was carefully considered. It was concluded that the possible error in either of these two figures could not detract from the significance of the results taken as a whole. For this reason, the curves shown in Figure 4 were drawn according to the recorded data.

The tests of Series B were made to determine the effect of sewage on the

TABLE VIII.—Sewage-Strawboard Waste Incubation Test; Series "A"

Days Incubation at 38° C.	5-Day B.O.D. at 20° C. (p.p.m.)					
	Sewage		Strawboard Waste		Waste+Sewage	
	Test Results	Average	Test Results	Average	Test Results	Average
0	262		540		567	
	296	279	550	545[1]	583	575
2	65		—		225	
	80		635		205	
	80		—		254	
	94	80[1]	620	628	240	231
4	90		600		110	
	140	115	670	635	100	105
6	20		510		<100	
	5	13	510	510	<100	<100
8	65		686		40	
	63	64	686	686	28	34
10	42		690		40	
	45	44	750	720	40	40
12	31		675		29	
	33	32	675	675	29	29
14	4		142		21	
	0	2	142	142[1]	17	19
16	18		457		20	
	20	19	428	442	21	20
18	0		394		—	
	0	0	350	372	17	17
20	89		56		3	
	80	85[1]	62	59	5	4

[1] Results questionable.

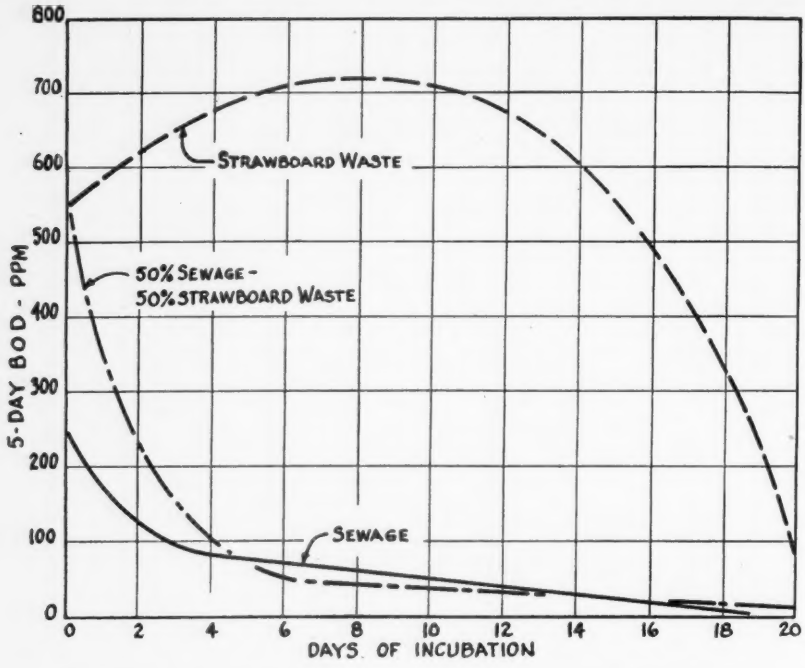

FIGURE 4.—Effect of sewage on B.O.D. reduction of strawboard waste.

B.O.D. reduction of strawboard waste and were run on a set of five sewage-strawboard waste mixtures. These tests were made in order to determine the effect of various concentrations of sewage on the rate of B.O.D. decrease in strawboard waste when allowed to stand.

The results of Test Series B are shown in Table IX.

TABLE IX.—Sewage-Strawboard Waste Incubation Test; Series "B"

Days of Incubation at 37° C.	5-Day B.O.D. at 20° C. (p.p.m.)				
	Strawboard Waste 100%	Strawboard Waste 75%; Sewage 25%	Strawboard Waste 50%; Sewage 50%	Strawboard Waste 25%; Sewage 75%	Sewage 100%
0	850	725	663	>544	>408
4	720	267	210	183	>267
8	719	83	87	73	220

The results of these tests (Series B) indicate that effective reduction of B.O.D. may take place in mixtures of 75 per cent strawboard waste with 25 per cent sewage.

Conclusions

1. Comparison of the nitrogen-phosphoric acid-potash (N–P–K) content of strawboard waste with that of Lea-Nichols dilution water suggests that the concentration of nitrogen bearing salts is too low for the satisfactory biological treatment of strawboard waste.

2. The character of the particles of strawboard waste makes it important that tests for suspended solids be run by identical methods to obtain comparable results.

3. Between 50 and 63 per cent of strawboard waste suspended solids can be removed on settling for one hour. Concentrations of these settled solids

have been found to vary from 2.0 to 2.8 per cent.

4. Forty-seven per cent of the strawboard waste B.O.D. is in a dissolved state.

5. The organic matter in strawboard waste appears to be oxidized at a rate comparable to that of sewage when supplemented dilution water is used.

6. Tests on the reduction of B.O.D. indicate that the rate of reduction in mixtures of sewage and strawboard waste is more rapid than in either sewage or strawboard waste alone.

Acknowledgments

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Stream Pollution

NATURAL PURIFICATION CHARACTERISTICS OF A SHALLOW TURBULENT STREAM *

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The data on which this article is based were obtained from a stream study designed to serve two purposes. It was undertaken in cooperation with the Tennessee Department of Public Health to determine existing conditions and the improvements needed to achieve satisfactory water quality in the stream. It was designed also to reveal fundamental factors involved in the natural purification of a highly polluted, shallow, turbulent stream.

The field and laboratory work was planned and conducted with utmost care. Every effort was made to obtain all information that was anticipated to be of value in achieving the stated objectives. The results answered many of the original questions, appeared to contradict some established concepts, and raised many new questions. It is the inevitable nature of research that any investigation designed to solve a given problem invariably reveals additional challenging problems.

A guiding principle in planning the study was that interpretation of the data would conform as closely as possible to the concepts developed by Streeter in his analysis of data obtained on the Ohio River (1) (2). Previous experience had indicated that some of the principles applicable to the deep, relatively sluggish Ohio would not apply to a shallow, turbulent stream, but more differences were found than had been anticipated.

The method of study, which included a number of unique details, and the results, which indicate a need for further detailed investigation of this type of stream, are believed to be of interest to all engaged in stream sanitation activities.

Description of Stream

The stream section involved is 42.7 miles long. Approximately 25 per cent of this mileage is riffles or rapids, and 75 per cent consists of shallow pools which average 3.60 ft. deep at low water stage. The average surface slope at low water stage is 2.96 ft. per mile and the average velocity during the study was 0.70 ft. per second.

The one major tributary increased the stream discharge in the section by about 10 per cent. Many smaller streams contributed to the additional increase in discharge from 620 c.f.s. at Mile 42.7 to 880 c.f.s. at Mile 0.0. Control of steam flow at a small upstream dam caused the discharge to fluctuate nearly 40 per cent in 24 hours.

Table I gives physical characteristics of individual sections between sampling stations.

Degree of Pollution

At the upper station, Mile 42.7, the stream had 4.82 p.p.m. B.O.D., 5.34 p.p.m. D.O., and an MPN of 4,100 coliform organisms per 100 ml.

Between Mile 42.7 and Mile 40.0 sewage from 28,000 persons and in-

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TABLE I.—Physical Characteristics of Stream Sections Between Sampling Stations

Section		Elevation Difference	Length	Slope	Average Velocity	Per Cent of Mileage		Ave. Depth Pools
From Mile	To Mile	(ft.)	(miles)	(ft. per mile)	(ft. per sec.)	Riffles	Pools	(ft.)
42.7	42.0	3.3	0.7	4.71	1.03	—	—	—
42.0	38.5	17.7	3.5	5.06	1.36	—	—	—
38.5	34.9	9.3	3.6	2.58	0.73	16.13	83.87	3.95
34.9	30.3	16.9	4.6	3.67	0.65	18.48	81.52	3.14
30.3	27.3	11.9	3.0	3.97	0.98	56.67	43.33	2.00
27.3	14.2	32.0	13.1	2.44	0.67	28.62	71.37	4.04
14.2	0.0	35.2	14.2	2.48	0.62	18.67	81.33	3.85
42.7	0.0	126.3	42.7	2.96	0.70	—	—	—

dustrial wastes contributed a combined 5-day 20° C. B.O.D. load of 72,450 lb. per day, or a population equivalent of 465,000. This would have increased the B.O.D of the stream to 26.3 p.p.m. if added at a single point. Natural purification reduced the B.O.D. so rapidly in this section that the maximum observed value at any station was 20.6 p.p.m.

None of the tributaries contributed important quantities of B.O.D. or coliform organisms. It was estimated that the combined B.O.D. from all tributaries was only 1,130 lb. per day.

Method of Study

A careful field survey was made before sampling started. Sampling stations were selected at intervals of about 3.5 miles in the upper 15 miles of the stream, where it was thought that conditions would be most significant. They were spaced about 13.5 miles apart in the lower portion, where it was thought that recovery would be well advanced.

Gaging stations, with continuous recorders, were established and rated at all sampling stations.

The distributions of wastes across the stream were investigated. At those sampling stations where the mixture of wastes was not complete each stream cross-section was divided into three or more subsections of equal discharge. Sampling points, marked by buoys, were established at the centers of the subsections, to insure representative sampling.

Two complete sets of samples were collected from all stations, and a third set was collected at stations from Mile 42.7 through Mile 27.3. For each set, samples were collected for 24 hours at 2-hour intervals, except at Mile 42.7 and on the major tributary, where the sampling intervals were 4 hours. The water that was sampled at Mile 42.0 below the first source of pollution, was identified as it passed and was followed downstream to and sampled at successive stations. This eliminated the wide range in stream conditions that frequently is encountered in the usual sampling program, consisting of daily or less frequent sample collection at each station over an extended period of time.

Detailed description of the methods used to identify the water under examination would require a separate article and only the principal method can be mentioned briefly. One of the wastes in the stream was a highly ionized chemical. Fluctuations in concentrations of this chemical gave fluctuations in electrical conductivity as the water passed a sampling station. These results, when plotted, gave a distinctive pattern. This pattern maintained its identity as the water passed downstream, and permitted identification at successive stations.

Gage height was recorded, and temperature, pH and dissolved oxygen

were determined for every sample upon collection. At each station where it was necessary to sample several points across the stream, equal portions from the individual points were composited every 2 hours into a single sample. Each 2-hour sample was composited in proportion to discharge with the three others collected in each 8-hour period. The 8-hour weighted composites were transported to a trailer laboratory, where determinations of 5-day B.O.D. and coliform organisms were started immediately. Color, turbidity and alkalinity also were determined in the trailer. Portions of the three 8-hour composites were proportioned to average discharges during the 8-hour periods and were combined to form a weighted 24-hour composite for each station. These were sent to the central laboratory for nitrogen, solids, and copper determinations. Long-term B.O.D. determinations were made on one complete set of 24-hour composites. Special samples were collected for plankton identification and counts. All samples were iced or otherwise preserved as necessary.

A special technique was used for both long-term and 5-day B.O.D. determinations. All samples were incubated as collected without dilution. A large volume of each sample was placed in an unstoppered bottle, from which B.O.D. bottles were filled as usual for initial and final D.O. determinations. The final D.O. was determined after a limited period of incubation that would not cause total oxygen depletion. When the final D.O. was determined another set of B.O.D. bottles was filled from the large bottle, which had been stored unstoppered in the incubator to permit continuing aerobic action. The process was repeated as necessary until the desired term of incubation was completed. For the long-term B.O.D., several B.O.D. bottles were incubated each time it was necessary to refill from the large bottle, to permit a final D.O. determination each day.

Presentation of Data

The most interesting features of the study are revealed by the D.O., B.O.D., and coliform results, and discussion is limited almost exclusively to these factors.

It is impractical to present the results of individual determinations here, and only 24-hour averages for one complete series are given in Table II. In spite of the care with which the work was conducted there were various circumstances, some not subject to control, that invalidated some of the individual results. The single set of values presented has been assembled here from the three sets available. It is believed to contain results most nearly representative of actual stream conditions.

Discussion of Results

Long-Term B.O.D.

The results of long-term B.O.D. determinations are presented graphically in Figure 1. The origin of the curve for each station below Mile 42.7 has been shifted on the horizontal axis to allow for the time of water travel from Mile 42.7 to that station.

The first stage of each curve was formulated by Thomas' Slope Method (3). Satisfactory fits of the observed points were not obtained in some cases. Trial and error adjustments were made to the calculated deoxygenation coefficients, k_b (bottle B.O.D. reaction rates), or the calculated first stage B.O.D. (L_b), or both, until reasonably satisfactory fits were obtained.

The second stage of each curve also was formulated by Thomas' method (4), with the intention of using the data in the interpretation of stream conditions. Subsequent discussion will show why these data were not used as planned.

The first stage deoxygenation coefficients k_b were used in the calculations of stream conditions. They were applied to the 5-day 20° C. B.O.D. results, as obtained on the trailer, to cal-

TABLE II.—Basic Hydrographic and Analytical Data

Station No.	1	2	3	4	5	6	7	8	9
Mile	42.7	42.0	38.5	Tributary	34.9	30.3	27.3	14.2	0.0
Discharge (c.f.s.)	620	620	670	80	750	780	780	810	880
Time Water Travel (hrs.)	—	1	4.75	5.75	12	22.5	27	55.5	89
Temperature (°C.)	20.7	24.5	23.7	20.3	23.1	23.2	22.8	22.5	21.5
Dissolved Oxygen (p.p.m.)	5.34	3.88	2.09	8.40	2.04	4.50	5.53	7.18	8.25
pH	7.2	6.9	7.2	7.6	7.5	7.3	7.6	—	—
Color (p.p.m.)	39	100	52	26	50	47	44	—	—
Turbidity (p.p.m.)	20	35	30	25	15	15	10	—	—
Alkalinity:									
Phenolphthalein (p.p.m.)	0	0	0	0	0	0	0	—	—
Total (p.p.m.)	45.7	69.6	81.6	54.5	81.5	84.3	84.8	—	—
B.O.D. (p.p.m.)	4.82	20.58	12.78	1.31	5.38	2.78	2.67	2.18	1.89
Coliforms (MPN per 100 ml.)	4,100	5,500	150,000	1,800	4,400	3,100	2,500	1,700	1,400
Nitrogen:									
NH_3 (p.p.m.)	0.982	0.791	0.595	0.072	0.511	0.546	0.506	—	—
Organic (p.p.m.)	0.687	1.02	1.055	0.168	0.482	0.629	0.771	—	—
$NO_3 + NO_2$ (p.p.m.)	3.545	3.47	3.30	0.592	2.48	2.50	2.45	—	—
NO_2 (p.p.m.)	0.097	0.111	0.112	0.0035	0.278	0.252	0.216	—	—
Suspended Solids:									
Total (p.p.m.)	7.2	24.4	34.8	8.8	10.0	10.8	10.0	—	—
Fixed (p.p.m.)	3.6	10.8	25.6	6.0	8.4	7.2	8.0	—	—
Volatile (p.p.m.)	3.6	13.6	9.2	2.8	1.6	3.6	2.0	—	—
Copper Water Soluble (p.p.m.)	0.080	0.020	0.0	0.0	0.0	0.0	0.0	—	-

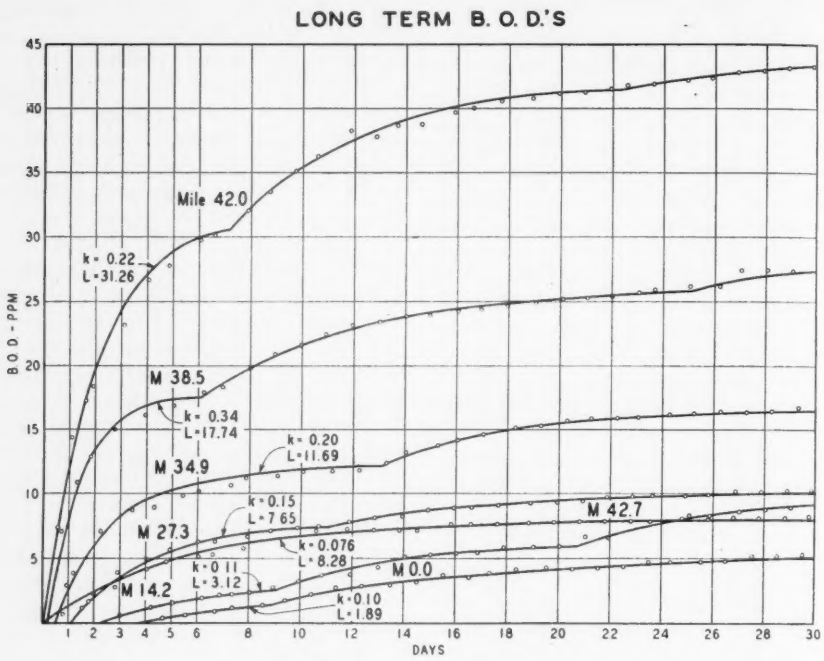

FIGURE 1.—Thirty-day B.O.D. curves.

culate first stage B.O.D. values at the sampling stations.

At one time it generally was believed that k_b did not vary far from 0.1 at 20° C. In this case k_b increased from 0.076 at Mile 42.7, above all pollution, to 0.34 at Mile 38.5 below all pollution, and then decreased to 0.095 at Mile 0.0.

Interesting relationships among the coefficients from Mile 38.5 to Mile 0.0 are shown in Figure 2. A plot of k_b against B.O.D. concentration on semi-logarithmic paper approximates a straight line. This suggests that the utilization of organic material as bacterial food may become more rapid as the concentration of food increases. When k_b is plotted against time of water travel below Mile 42.7 a smooth curve may be drawn through the points. In this graph the curve was stopped at the point for Mile 34.9, although it could have been continued smoothly through the point for Mile 38.5. Continuation through this point would indicate that the curve would become asymptotic to the horizontal axis. This would mean that the coefficient would become infinitely great as the time below the entrance of pollution approached zero. This does not appear to be logical. It is suggested that the entrance of the major tributary below Mile 38.5 may influence the downstream coefficients in such a way that they are not comparable with that for Mile 38.5 on a time basis.

B.O.D. in Stream

The first stage B.O.D. at each station was calculated from the 5-day B.O.D. by the formula:

$$L_{20} = \frac{X_5}{1 - 10^{-k_b t}}$$

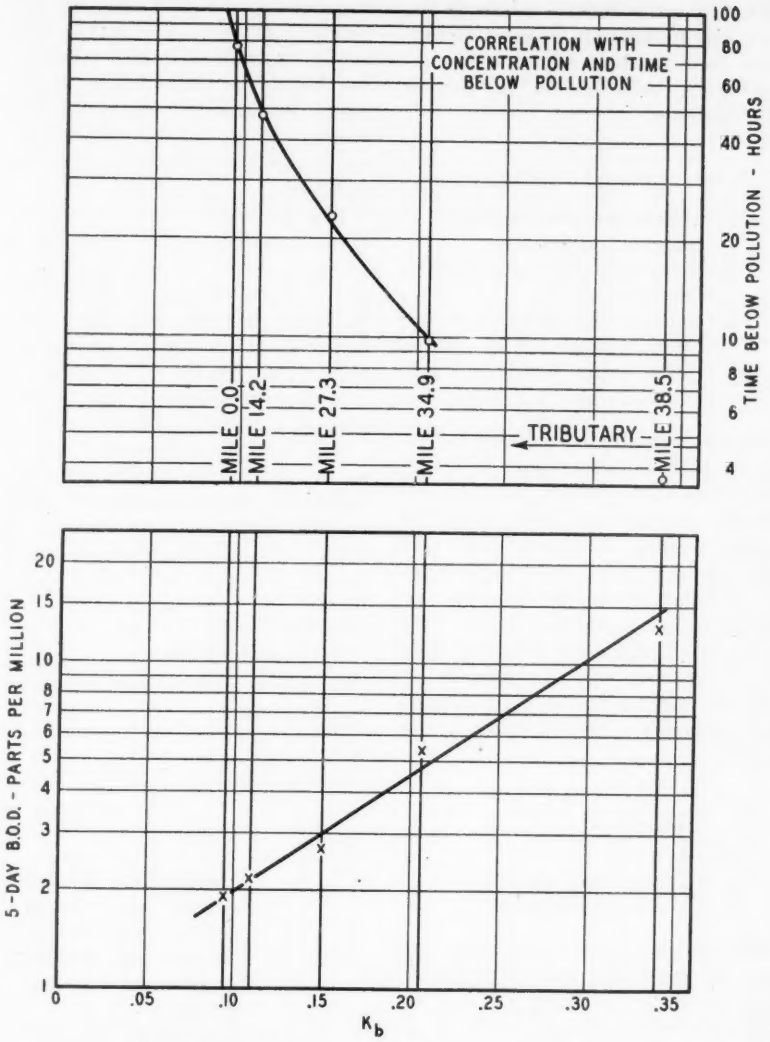

FIGURE 2.—Laboratory B.O.D. reaction coefficients.

where

L_{20} = First stage B.O.D. at 20° C.
X_5 = 5-day 20° C. B.O.D.
k_b = Deoxygenation coefficient for sampling station determined from long-term B.O.D.
t = Time = 5 days.

This value was converted to first stage B.O.D. at the stream temperature by the formula:

$$L_T = L_{20}[1 + 0.02(T - 20)]$$

L_T = First stage B.O.D. at stream temperature.
T = Stream temperature in °C.

The first stage B.O.D. values at the upper and lower ends of each stream section were used to calculate the deoxygenation coefficient for the section by the formula:

$$k_1 = -\frac{1}{t}\log\frac{L_B}{L_A}, \text{ where}$$

k_1 = Deoxygenation coefficient at stream temperature.
t = Time of water travel through section in days.
L_B = First stage B.O.D. for station at lower end of section.
L_A = First stage B.O.D. for station at upper end of section.

The necessity for corrections for inflow of both pollution and tributary water made it impossible to apply this formula directly to the data. A graphic method combined with trial and error calculations was used to obtain satisfactory fits of the data, including inflow allowances. The basic mathematical principle followed, however, is expressed by the formula.

The k_1 values at stream temperatures were converted to 20° C. values by the formula:

$$k_{20} = \frac{k_T}{1.047^{(T-20)}}, \text{ where}$$

k_{20} = k_1 at 20° C.
k_T = k_1 at stream temperature.
T = Stream temperature.

The results of these calculations, with some of the basic and intermediate data, are given in Table III and are plotted in Figure 3.

The k_1 values in the upper stream sections possibly are greater than any previously reported for a stream. Sedimentation probably contributed to the size of some of them, although most of the unstable organic materials in the industrial wastes are believed to be soluble. But sedimentation alone cannot account for the rapid rates of purification observed. There was 80 per cent reduction in B.O.D. in one-half day's time of water travel below the major source of pollution, and 89 per cent in one day. The B.O.D. concentration at Mile 30.3, 15.3 miles or one day below the major source, was 2.04 p.p.m. less than it was above all pollution. This indicates a B.O.D. reduction of 109.5 per cent of the added pollution.

It is probable that biological slimes found attached to the stream bed were a major factor in the rapid rates of B.O.D. reduction. The turbulence of the water brought it in frequent contact with these slimes. This probably allowed absorption of organic matter in a manner similar to that which occurs in a trickling filter.

The k_1 values decreased from 2.26 at 20° C. in the section immediately below the major source of pollution to 0.017 in the last section downstream. This will receive especial comment later.

Dissolved Oxygen

Reaeration coefficients for the various stream sections were calculated by the formula:

$$D_t = \frac{k_1 L_A}{k_2 - k_1}(10^{-k_1 t} - 10^{-k_2 t}) + D_A \cdot 10^{-k_2 t}$$

where

D_t = Dissolved oxygen deficiency (adjusted for stream temperature and elevation) at lower end of section, corresponding to time of water travel t.
k_1 = Calculated deoxygenation coefficient at stream temperature.
k_2 = Reaeration coefficient at stream temperature.
D_A = Dissolved oxygen deficiency (adjusted) at upper end of section, corresponding to first stage B.O.D. L_A.

The accepted use of this formula in calculating k_2 involves a combination of graphic and trial and error methods.

TABLE III.—Deoxygenation and Reaeration Calculations

River Mile	Station	Sum of Time of Flow (days)	Water Temp. (°C.)	Discharge (c.f.s.)	B.O.D. 5-Day B.O.D. P.P.M.	B.O.D. 5-Day B.O.D. Lb. per Day	k_b	L_1 (20°)	L_1 (T)	k_1 (T)	k_1 (20°)	Dissolved Oxygen P.P.M.	Dissolved Oxygen Lb. per Day	Saturation Per Cent	Saturation Lb. per Day	Saturation P.P.M.	Oxygen Def. (lb./day)	k_2 (T)	k_2 (20°)	Elevation (ft.)
42.7	Bridge	0	20.7	620	4.82	16,140	0.076	27,685	28,075			5.34	17,880	61.7	28,995	8.66	11,115			1180
	Industrial Waste					60,000	0.18	68,650	76,755											
–	Ind. Wastes and Sewage					170	0.10	250	250											
	Ind. Wastes					130	0.10	190	190											
						76,440	0.139	96,775	105,270	2.77	2.26						11,115	16.66	15.52	
42.0	Bridge	0.04	24.5	620	20.58	68,900	0.22	74,810	81,540			3.88	12,990	47.9	27,120	8.10	14,130	7.88	7.34	1180
			24.5			39,095	0.22	42,450	45,930				8,100	29.9	27,120		19,020			
40.3	Sewage	0.13	22.5	50		5,170	0.10	7,560	8,165			4.2	1,135	50	2,270	8.40	1,135			
	Ind. Waste					12,155	0.10	17,770	18,230											
			24.3			56,420	0.155	67,780	72,325	2.21	1.84		9,235	31.4	29,415	8.13	20,180	5.56	5.22	
38.5	Boat Station	0.20	23.7	670	1.278	46,240	0.34	47,190	50,680			2.09	7,560	25.4	29,740	8.22	22,180	1.313	1.244	1160
38.0		0.24		670					46,135	1.02	0.873		6,415	21.1	30,340		23,925			
	Tributary	0.24	20.3	80	1.31	570	0.09*	1,300	1,310			8.40	3,630	96.0	3,780	8.75	150			1160
38.0				750					47,445				10,045	29.4	33,535	8.42	24,075			
34.9	Boat Station	0.50	23.1	750	5.38	21,790	0.20	24,210	25,710			2.04	8,260	24.6	33,655	8.31	25,395			1150
									19,380	0.558	0.482						20,255	0.995	0.947	
	Side Drainage	0.72	20	30	0.8	130	0.06	190	200			8.38	1,360	96	1,415	8.73	55			
									19,580								20,310			
30.3	Boat Station	0.94	23.2	780	2.78	11,710	0.16	13,905	14,760			4.50	18,955	54.2	34,960	8.30	16,005			1135
27.3	Bridge	1.13	22.8	780	2.67	11,250	0.15	13,690	14,460	0.047	0.041	5.53	23,290	66.1	35,255	8.37	11,965	0.715	0.684	1120
			22.7						14,090	0.019	0.017		27,325	77.4	35,295	8.38	7,970	0.327	0.314	
	Side Drainage	1.72	20	30					200			8.38	1,360	96	1,415	8.74	55			
									14,290				28,685	78.1	36,710	8.40	8,025			
14.2	Boat Station	2.31	22.5	810	2.18	9,535	0.11	13,260	13,925											1090
									13,505											
	Side Drainage		20	70					470			8.40	3,175	96	3,310	8.75	135			
									13,975											
0.0	Bridge	3.71	21.5	880	1.89	9,000	0.10	13,160	13,555						40,725	8.57				1060

* Lag 2.2 days.
Values of time, temperature, discharge, P.P.M. which are underlined are observed values.

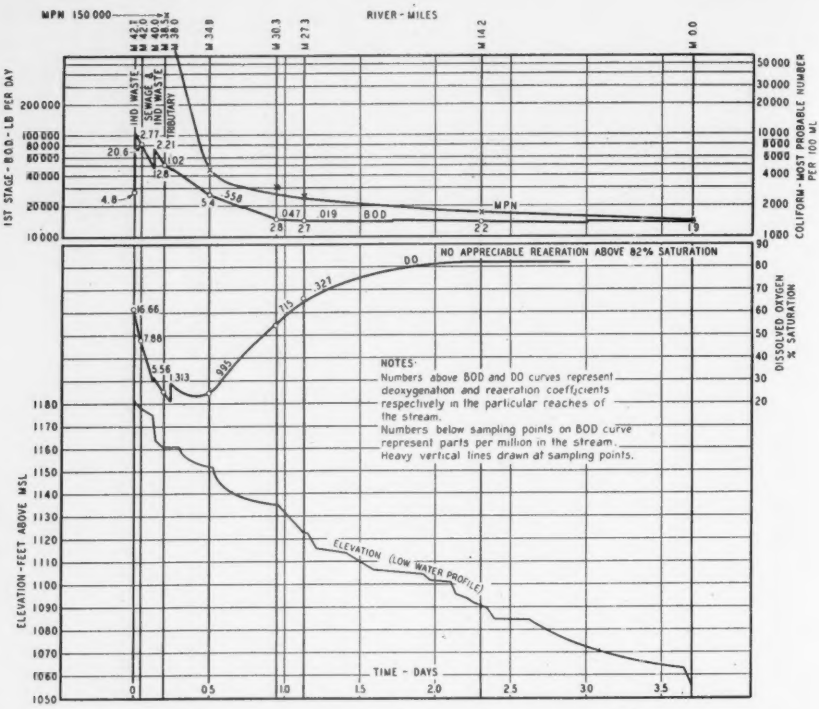

FIGURE 3.—Diagram of natural purification characteristics.

An expansion of these methods was necessary to allow for inflows of pollution and tributary water.

The k_2 values at stream temperatures were converted to 20° C. values by the formula:

$$k_{20} = \frac{k_T}{1.0159^{(T-20)}}$$

where

$k_{20} = k_2$ at 20° C.
$k_T = k_2$ at stream temperature.
T = Stream temperature.

The calculations involve an assumption that requires explanation regarding the utilization of dissolved oxygen by settled bottom deposits and organic matter absorbed in biological slimes. Streeter (1) examined the action of sludge deposits in his analysis of natural purification phenomena. He developed the concept that accumulated sludge deposits, after a sufficient period of reasonably constant conditions, exerted a daily demand on the dissolved oxygen of the stream equal to the amount of B.O.D. added to the deposits each day. He formulated the process mathematically and proved the formulations by application to stream data with remarkable agreement between observed and calculated values. This assumption simplifies the calculation of stream coefficients. It implies that the effects of bottom deposits may be disregarded and the coefficients can be calculated from the observed values at the upper and lower ends of a section.

Unfortunately this assumption does not appear to apply to the stream under examination. It results in k_2 values in three sections between Mile 42.6 and Mile 38.5 that range from 15.52 to

5.22 at 20° C. The physical characteristics of this portion of the stream are not markedly different from the downstream sections where more reasonable values of 1.244 to 0.314 were obtained.

The times of water travel, especially in the upstream sections, were so short that large errors in k_2 values would result from small errors in time. Even if the times of travel were uniformly low by as much as an improbable 100 per cent, however, the calculated k_2 values still would be unaccountably high.

Reasonably constant stream conditions may not have existed long enough before the study started for the accumulated bottom deposits to exert their maximum daily oxygen demand. Streeter (1) estimated that the necesary period of accumulation was between 15 and 100 or more days, depending on the unknown rate of decomposition of the bottom deposits. Average daily stream discharges had been reasonably constant for 53 days when the last set of samples were collected. Stream temperatures probably dropped 5° or 6° C. during the same period. No other probable variations in conditions are known. Even a conservative estimate that the bottom deposits had accumulated only long enough to exert 50 per cent of their potential ultimate daily oxygen demand would yield calculated k_2 values that would be excessively high.

The only acceptable conclusion appears to be that large portions of the bottom deposits decompose and escape without utilizing disolved oxygen from the stream water. If this be true, the actual amount of dissolved oxygen utilized in a stream section where bottom deposits exist cannot be calculated from observed B.O.D. and D. O. results at the ends of the section, and the initial assumption regarding oxygen utilization by bottom deposits results in fictitious reaeration coefficients. The term "deoxygenation" used to designate the coefficient k_1, therefore may be misleading when applied to this type of stream. This designation implies that it represents a withdrawal of dissolved oxygen from the stream water. Actually, in this stream it appears to represent only a reduction in the amount of B.O.D. carried in the water. If so, it cannot be used in the oxygen sag curve formula as a true measure of withdrawal of dissolved oxygen.

Numerous references can be cited to support the logic of this suggestion. Symons (5) incubated a number of solutions of pure organic compounds anaerobically and identified and measured the evolved gases. He reported that the compounds liberated large portions of their carbon and hydrogen as methane gas. Both of these elements are potential utilizers of dissolved oxygen to form carbon dioxide and water under aerobic conditions. Fair and associates (6) have noted that evolved methane and free hydrogen gases may represent as much as 42 per cent of the original potential oxygen demand of sludge decomposed under conditions simulating those at the bottom of a stream. The production of methane and hydrogen in the anaerobic digestion of sewage sludge is well known. It is generally accepted that anaerobic decomposition occurs in the deeper layers of stream bottom deposits. One of the chief constituents of the major industrial waste in this stream was an organic compound that could decompose anaerobically to carbon dioxide and water without the use of any oxygen other than that contained in the compound.

This discussion indicates why second stage B.O.D. values were not used in calculating deoxygenation and reaeration coefficients. In planning the study it was reasoned that second stage as well as first stage material might be deposited on the stream bed. If so, it appeared logical that calculations of the coefficients should include the dis-

solved oxygen utilized by the decomposition of second stage deposits. The data indicate that deposition of second stage material did occur, since there were reductions in second stage B.O.D. in upstream sections where there was no evidence of exertion of second stage demand in the stream water. However, Fair and associates (6) reported the loss of as much as 17 per cent of the potential oxygen demand of bottom deposits as oxidizable ammonia. This is comparable to the loss of potential demand by evolution of methane and hydrogen. The inclusion of deposited second stage demand in the calculations would have given higher deoxygenation coefficients and consequently higher reaeration coefficients than those which already have been rejected as too high.

Reaeration coefficients probably are reliable only in those stream sections where any existing bottom deposits decomposed aerobically. These sections cannot be defined exactly from available information, but it appears reasonable that there were no appreciable bottom deposits in sections where the laboratory deoxygenation coefficient k_b equalled or exceeded the stream coefficient k_1. This occurred in sections between Miles 30.3 and 0.0, where B.O.D. stabilization was nearing completion. The dissolved oxygen in the section between Miles 27.3 and 14.2 apparently reached and remained at its maximum observed saturation value several miles above the lower end of the section. Thus the time of water travel through the section did not represent accurately the time required for the dissolved oxygen to attain the value observed at Mile 14.2. For this reason the calculated k_2 of 0.314 at 20° C. for this section may be low. The only reasonably representative k_2 for any section is believed to be that of 0.684 for Mile 30.3 to Mile 27.3. This section had a relatively high percentage of riffles and a high stream velocity. It is probable that a representative average k_2 for the entire stream would be lower than this, possibly between 0.5 and 0.6.

The maximum dissolved oxygen saturation value obtained was 82 per cent. The stream maintained but did not exceed this value for many miles in the lower portion of the stream, in spite of a high reaeration capacity and a negligible exertion of B.O.D. Moore (7) reported that constituents of sewage lowered the dissolved oxygen saturation equilibrium for mixtures of water and sewage. The data indicate a comparable condition in this stream. The oxygen saturation equilibrium is a controlling factor in the oxygen sag curve formula. The formula utilizes the results of dissolved oxygen determinations in terms of oxygen saturation deficiencies. These deficiencies usually are based on tables of saturation values for distilled water. An error is introduced into the calculations if the assumed saturation values do not represent actual stream water saturation values. It is possible that the greatest attainable accuracy can be achieved only by determining experimentally the true oxygen saturation values for the stream under examination. These values would be used in calculations involving D.O. deficiencies instead of the distilled water values ordinarily used.

Coliform Organisms

The method of sampling and compositing used resulted in relatively few samples for coliform organism determinations at each station. The wide range over which bacterial concentrations may vary at a given station is well known. Indeterminate results were obtained on some samples because the dilutions used were inadequate to cover the ranges of coliform concentrations. The laws of chance distribution of bacteria in water, on which the theory of M.P.N. is based, indicate that the estimated M.P.N. values on equal portions of the same sample may vary

over a wide range. In this study if any one result was indeterminate or fell near either extreme of the range of possible M.P.N. results it could throw the average for a station out of line with representative results at other stations. Probably the examination of a large number of samples collected at random over a long period of time, or the examination of a large number of portions from each of the limited number of samples obtained in this study, would have given more satisfactory results.

It was necessary to combine coliform results from two sets of samples to obtain a typical death rate curve. Values for Mile 38.5 through Mile 34.9 from one set were combined with values for Mile 30.3 through Mile 0.0 from another set. The two values at Mile 30.3 for the two sets differed by only 10 per cent. The stream discharges and times of water travel for the two sets were nearly identical.

The M.P.N. values were converted to quantity units, which placed all results on a comparable basis, despite increasing stream discharge within the section. The quantity units were converted to the percentages that they represented of the maximum observed value which occurred at Mile 38.5. These values plotted against time on semilogarithmic paper, give the curve presented in Figure 5. This curve can be fitted satisfactorily by the formula for bacterial death rates developed by Streeter (8):

$$y = a(10^{-bt}) + c(10^{-dt})$$

where

y = percentage of maximum observed coliform value remaining after time t in hours.

a, b, c and d = constants.

The rates of coliform reduction indicated by the first portion of this curve were quite high, with only 2 per

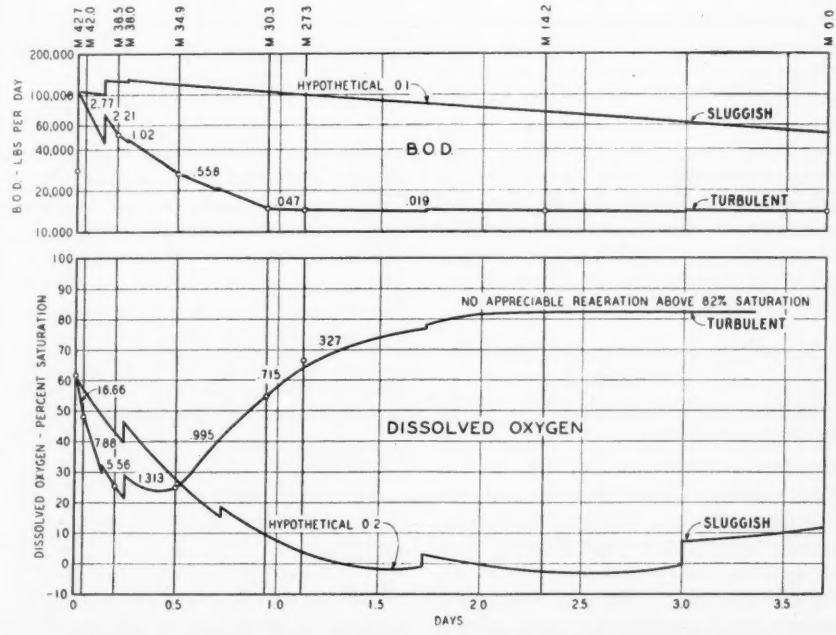

FIGURE 4.—Relative recovery capacities of turbulent and sluggish streams.

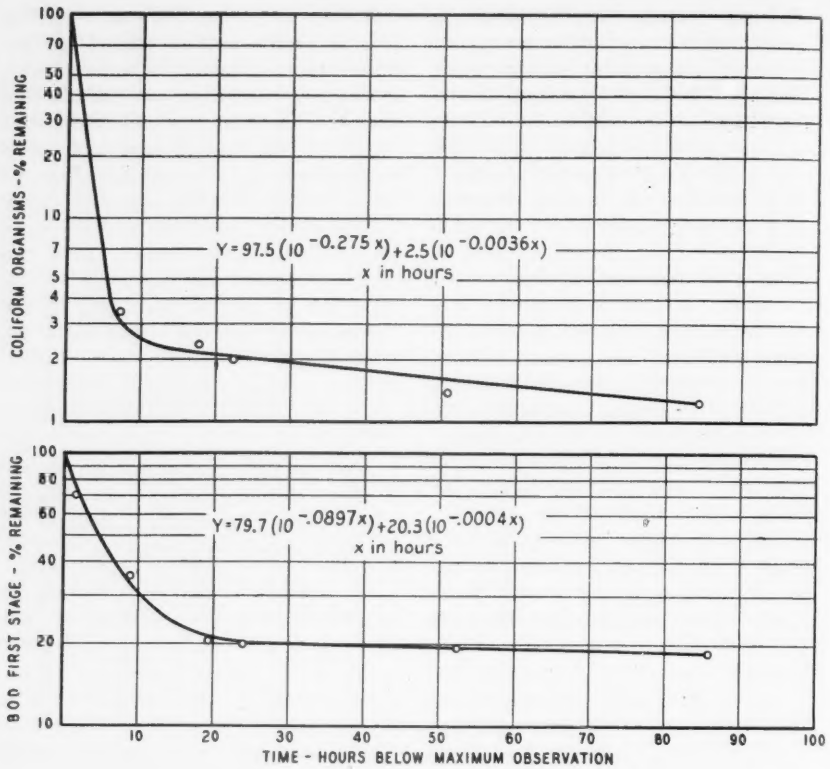
COLIFORM ORGANISMS - % REMAINING
Y = 97.5 (10 -0.275 x) + 2.5 (10 -0.0036x)
x in hours
BOD FIRST STAGE - % REMAINING
Y = 79.7 (10 -.0897x) + 20.3 (10 -.0004x)
x in hours
TIME - HOURS BELOW MAXIMUM OBSERVATION

FIGURE 5.—Comparison of coliform death rate and B.O.D. reduction.

cent remaining at the end of one day. The rates probably reflect the effects of sedimentation and absorption previously discussed. The limitations described above must be remembered in judging the reliability of the actual numerical values obtained.

Turbulent and Sluggish Streams Compared

Most of the present-day concepts of natural purification are influenced by the factors developed by the United States Public Health Service in its excellent studies of pollution and natural purification in the Ohio River. It is interesting to compare the results obtained on the shallow and turbulent stream with calculated results for a hypothetical deep and sluggish stream similar to the Ohio River. The same oxygen deficiency and B.O.D. above the sources of pollution, and the same temperatures and additions of pollution and tributary dilution found in this study are assumed for the hypothetical stream. The main difference is that coefficients of $k_1 = 0.10$ and $k_2 = 0.20$ at 20° C. are used for the hypothetical stream. The calculated results are shown graphically in Figure 4.

Biochemical Oxygen Demand

The rapid disappearance of B.O.D. from the water of this stream, with a reduction of 109.5 per cent of the added B.O.D. in one day, contrasts decidedly with the much slower reduction in the hypothetical stream, where there is a reduction of only 22.5 per

cent in one day and 53.4 per cent in three days.

Dissolved Oxygen

The turbulent stream reached its minimum dissolved oxygen content of 21 per cent saturation in 0.25 day and recovered to 58 per cent saturation in one day. In 2.25 days it attained its maximum observed degree of saturation at 82 per cent. The hypothetical curve descends to 7 per cent saturation in one day and to total depletion in a little less than 1.5 days. Total depletion continues for about 1.5 days and the curve recovers to only 10 per cent saturation in 3.5 days.

This indicates the difference in the capacities of the two types of streams to assimilate organic pollution without excessive dissolved oxygen depletion. The greater assimilative capacity of the turbulent stream is due partially to its greater reaeration capacity. It appears that the ability of this stream to reduce high concentrations of B.O.D. very rapidly, possibly by absorption of organic material in bottom slimes, tends to counteract its favorable reaeration capacity. The bottom deposits concentrate the oxygen demand in those sections where they occur, and add their dissolved oxygen requirements to those of the B.O.D. exerted normally in the stream water. Evidence has been offered which suggests that the deposited organic material may not exert all of its potential demand on the oxygen of the stream, but that a portion of it may be converted anaerobically to unoxidized gases that escape from the stream. If this be true, it partially counteracts the adverse effects of the bottom deposits.

Coliform Organism Death Rates

Comparison of coliform death rate constants for the Ohio River below Cincinnati (8) with those obtained in this study indicates that the rates were much greater in this stream immediately below the source of sewage:

Constant	Numerical Value	
	Ohio River	This Stream
a	99.51	97.5
b	0.0195	0.275
c	0.49	2.5
d	0.00242	0.0036

The comparison may be made also in terms of percentages remaining at the ends of selected periods of time. In the Ohio River 64 per cent remained after 10 hours, compared to 2.5 in this stream. After 20 hours the respective values were 41 and 2.1 per cent. The downstream rates in this stream were lower than those in the Ohio and after 100 hours the values were relatively close together at 1.4 and 1.1 per cent.

Formulation of Biochemical Oxygen Demand Curve in Stream

The first stage B.O.D. values in the stream exhibited an extremely interesting relationship. The results, in thousands of pounds per day at each station, were converted to the percentages that they represented of the calculated value at Mile 40.0 where the last major waste entered the stream. These results, plotted against time of water travel on semi-logarithmic paper, are shown in Figure 5. The curve closely resembles a typical bacterial death rate curve and can be fitted by the same method of formulation:

$$y = 79.7(10^{-0.0897t}) + 20.3(10^{-0.0004t})$$

where

y = Percentage of first stage B.O.D. (calculated for Mile 40.0) that remains at end of time t, in hours.

This indicates that the rate of B.O.D. reduction diminished progressively with time below the source of pollution. If this be true, the deoxygenation coefficients k_1 calculated for the various sections of the stream were not constants as the method of calculation

implies. Each k_1 represented, instead, the average of the constantly diminishing rate for the individual stream section.

It is possible that the first steep portion of the curve may be due principally to the reduction in B.O.D. through deposition on the bottom, while the second portion may represent more nearly normal action in the stream water. The two phases may represent two distinct types of B.O.D. reduction rather than one type which proceeds at a progressively diminishing rate. It probably is premature, therefore, to suggest that this may represent the typical course of B.O.D. reduction even in streams in which deposition does not occur. There is a certain logic, however, in the thought that there may be a definite correlation between the B.O.D. reaction and the fate of the organisms that support it.

Summary

Generalizations based on limited data are dangerous, especially when they indicate conclusions that are contrary to accepted concepts. The boundaries of this article, which have been established arbitrarily, could be expanded by venturing further into theories which are suggested, but not fully supported by the available data.

The extremely detailed method of study justifies more confidence in presenting the data than would be the case if they had been obtained by the usual random sampling method. It is believed that they at least are reasonably representative of the condition of the stream during the period of sampling.

This article is not offered as a final answer to the questions it raises. It is offered in the hope that it will stimulate others to assist in the research needed to solve the problems involved in maximum utilization of the relatively great capacities of shallow turbulent streams to assimilate pollution. It is believed that the research will yield rich dividends in the form of more economical treatment plants for wastes discharged into this type of stream.

The following conclusions indicate some, but not all of the factors which require further investigation:

1. The laboratory deoxygenation coefficients k_b varied approximately with the 5-day B.O.D. concentrations of the samples collected below all sources of pollution. The range was 0.34 to 0.095 for B.O.D. results of 20.6 to 1.89 p.p.m.

2. The stream deoxygenation coefficients k_1 were many times greater than the laboratory coefficients for some distance below the sources of pollution. Still farther downstream the relationship was reversed. The range of the stream coefficients was 2.26 to 0.017 at 20° C.

3. The rate of reduction in B.O.D. was much more rapid in this stream than in the usual deep, sluggish stream. The reduction was about seven times as great for 0.5 day and four times as great for one day.

4. The rate of first stage B.O.D. reduction in the stream water followed the normal course of bacterial death rates. This indicates that the rate was not constant but diminished progressively with time below the entrance of pollution.

5. It is suggested that the rapid reduction in B.O.D. may be due partially to the absorption of organic material in biological slimes on the bed of the stream.

6. The assumption that all deposited material exerted its full potential demand on the dissolved oxygen of the stream water resulted in obviously excessive reaeration coefficients k_2 that ranged from 15.52 to 5.22 at 20° C. It is suggested that portions of the deposited material may have decomposed anaerobically and escaped from the stream as unoxidized gases, without utilizing oxygen from the stream water.

7. Only one stream section yielded a

calculated reaeration coefficient that is believed to represent accurately the reaeration capacity of the section. This value, 0.684 at 20° C., was obtained in a section with more riffles and a higher velocity than the averages for the stream. A more nearly representative average for the entire stream possibly would fall between 0.5 and 0.6.

8. This stream could assimilate more organic pollution without excessive dissolved oxygen depletion than could a deep sluggish stream. Some of the factors that affect the assimilative capacity appear to be:

(*a*) High reaeration coefficients that increase the assimilative capacity.

(*b*) Concentration of B.O.D. through deposition on the bed of the stream, which tends to decrease the assimilative capacity.

(*c*) Elimination of a portion of the deposited material without utilization of dissolved oxygen, which tends to counteract the concentration of B.O.D. and increase the assimilative capacity.

9. The coliform death rates for this stream were similar to those for the Ohio River, but were higher immediately below pollution and lower farther downstream. After 10 hours only 2.5 per cent of the coliforms remained, compared to 64 per cent in the Ohio. After 100 hours comparable values were 1.1 and 1.4 per cent.

10. The relatively few samples examined for coliform organism in this study probably did not yield altogether dependable M.P.N. averages. Because of the wide range of possible values inherent in the estimation of the M.P.N a much larger number of individual examinations should be made to ensure representative averages.

Acknowledgments

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All hydrographic data, including identification of the portion of water under examination as it passed downstream, were provided by the Hydraulic Data Division of the Water Control Planning Department, Tennessee Valley Authority.

Especially recognition for indirect but very real contributions to this study is due G. R. Scott, formerly in charge of the Stream Sanitation Staff. He was one of the first to recognize and prove the wide variations that occur in laboratory and stream deoxygenation coefficients. Many of the features of this article are the results of his original thinking and critical examination of generally accepted concepts.

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NATURAL PURIFICATION OF A SHALLOW TURBULENT STREAM—A DISCUSSION

By George E. Symons

Associate Editor, Water and Sewage Works, New York City

Certainly this paper is an outstanding contribution to our knowledge of self-purification of streams. At the same time that we realize the tremendous amount of work that went into this study by Mr. Kittrell and his staff, we must appreciate the difficulties that may be expected in any attempt to make a large scale experiment out of a natural stream. Likewise, we must appreciate the difficulties in attempting to correlate laboratory and field data, particularly when one is dealing with biochemical oxygen demand. These are two of the important implications of the work represented by the paper.

This latter observation becomes apparent when one compares the deoxygenation constants obtained in the laboratory studies with those obtained in the field. For example, these data indicate the deoxygenation constant in the stream to be more than ten times that obtained in the bottle. Thus again we see that what happens in a stream cannot be duplicated in a bottle.

Certain other observations from Kittrell's study deserve more than passing comment. It should be reemphasized that this study made use of proportional sampling of the cross-section of the stream. Furthermore, the sampling of the stream was so proportioned to flow that any particular sample at any particular point represented original pollution at a previous time, equal to the flow time to that point at that elevation and velocity of flow. In spite of these precautions as to sampling and the compositing of samples over three 8-hour periods to compensate for diurnal effects and variations in flow, the data obtained were not always usable.

The method of determining long-term B.O.D.'s by incubating the sample in a large open bottle from which samples are drawn at intervals for the determination of 5-day B.O.D. seems unique. One may wonder if this procedure has any effect on the difference in rate of deoxygenation between the bottle tests and the stream tests.

Probably the most outstanding observation to be made about the data is the wide and rapid variations in the k values in the deoxygenation formula as the water progresses downstream. This wide variation was noted both in the laboratory tests and in the stream, the variations in the stream being from 2.26 to 0.017 (at 20° C.). The authors have given several possible reasons for this variation of a constant that apparently is not a constant at all. These possible factors are listed as (1) sedimentation of some of the oxidizable matter, (2) oxidation of dissolved and colloidal matter by slimes attached to the bed of the stream, (3) anaerobic digestion (oxidation) of organic matter within sludge beds, and (4) more rapid

utilization of organic food by bacteria when the concentration of food is high.

As noted by the authors, Streeter had postulated that sedimentation was not a factor because the "sludge deposits . . . exert a daily demand on the stream equal to the amount of the B.O.D. added to the deposits each day," but the paper under discussion indicates that this apparently is not so. They cite the work of Fair on sludge deposits and of this discussor on the methane fermentation of organic compounds, to show that, under anaerobic action, organic matter may be converted to carbon dioxide, methane, and ammonia which, when released to the stream above, do not exert an oxygen demand on the stream. Thus it appears that sedimentation plus anaerobic oxidation (wet burning) can materially affect the deoxygenation coefficient or rate of satisfaction of B.O.D. in a stream.

In this same connection it may be pertinent to inject the idea that perhaps different organic compounds have different rates of oxidation by bacteria, *i.e.*, bacteria attack the more easily oxidized matter first, with the less easily oxidizable matter being left until later (further downstream).

That bacteria do oxidize organic matter at different rates was evidenced in studies by this discussor with Dr. A. M. Buswell at the University of Illinois in 1928–32. In aerobic oxidation in B.O.D. bottles, pure soaps of fatty acids showed an average k value of 0.0324. Variations were from 0.0192 to 0.0408, with the simpler fatty acids having the higher k values. In anaerobic oxidation (the methane fermentation) the rate of decomposition by bacteria was often affected by the complexity of the organic molecule or its bacteriostatic effect.

The concept that rates of oxidation may be higher at higher concentrations of organic bacterial food may need further scrutiny. It is true that bacterial populations increase and die off with some relation to concentration of food supply. Perhaps it may be true that high concentrations of bacteria may destroy a given quantity of organic matter in less time than low concentrations, but there is no reason to believe that the life process of an individual bacterium proceeds faster in the presence of higher concentrations of food. On the other hand, at lower concentrations of both food and bacteria, the rate of disappearance of organic matter may be affected by the random chance of contact between food and organism, but once that contact is made the bacterial oxidation probably proceeds at the rate dependent on the life process of the organism. Temperature, of course, is a factor in this.

On the basis of the authors' work it appears that in self-purification studies we cannot ascribe a single curve of a particular type to fit all streams and all conditions. It has been intimated that perhaps this deoxygenation or B.O.D. satisfaction curve is not a first order reaction at all. There are yet many factors to be evaluated.

THE OPERATOR'S CORNER

CONDUCTED BY S. C. MARTIN

MANAGED MAINTENANCE INSURES OPERATING EFFICIENCY

There is no gainsaying the excellent job of plant operation most sewage works men are doing today. Higher plant effluent standards are being achieved than ever before, and routinely so. The same objective appraisal of the upkeep aspect of plant administration, however, reveals that the average sewage works operator is not doing a comparable job of maintenance of mechanical and physical equipment.

Harrassed many times by lack of personnel, the responsibility for more than one job, and disinterested municipal officials, the average sewage works operator is tempted to defer adequate care of equipment in favor of what seem to be more urgent duties. As a result, equipment care programs frequently become repair programs. The elements of management —intelligent, planned, economical control—are lacking.

The unfortunate aspect of this is that proper upkeep of sewage works will pay its own way and will return dividends in time, money, and operating efficiency. Time spent in this manner is not a loss, but an investment. Managed maintenance—a positive program entailing the performance of active measures for insuring equipment efficiencies—will minimize wear, forestall breakdowns, and postpone replacements.

Managed maintenance means intelligent maintenance! A thorough understanding of the construction and operation characteristics of equipment and structures is basic for their continued efficient operation and upkeep. Without such knowledge any program for equipment care becomes only a guess-work proposition. With such knowledge ineffectual and harmful practices are eliminated.

Managed maintenance means a planned program! Knowledge without a workable plan for its use is of little value. Adequate planning for maintaining sewage works machinery involves an actual listing and scheduling of all upkeep requirements and a physical recording of the work accomplished, as contrasted with the prevalent practice of carrying such schedules and records in mental files cluttered by faulty memories. Planned sewage works upkeep results in "shooting trouble" instead of "trouble shooting."

Managed maintenance means economy! Over-all economy of plant operation always results when equipment is properly cared for. Intelligently planned, such care will prevent the practice of operating equipment past its economical life span because adequate and accurate cost records are not available. Economical maintenance requires periodic comparison of upkeep and operation costs with those of replacement equipment.

Perhaps if maintenance failures were as quickly and dramatically apparent as operating failures, proper care of equipment and structures would receive its just share of the sewage works operator's time and energy. This, however, is certain: only managed maintenance—intelligent, planned, economical maintenance—can insure the continuous, efficient operation of sewage works.

S. C. M.

SEWAGE TREATMENT AT SOUTH ST. PAUL, MINNESOTA *

By W. H. Cropsey and K. D. Larson

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Many persons confuse the South St. Paul sewage treatment plant with the Minneapolis-St. Paul Sanitary District plant. The latter treats the sewage from Minneapolis and St. Paul, while the former handles the sewage and industrial wastes from the city of South St. Paul, a separate city adjacent to and southerly from the St. Paul city limits.

Prior to 1940, the large packing plants of Armour and Swift and several small packing plants in the city of South St. Paul discharged their wastes into the Mississippi River without treatment. This was not an intentional misuse of public property, since for many years it appeared that the 11,800-sec. ft. average flow of the Mississippi River was large enough to take care of the sewage of Minneapolis, St. Paul, and South St. Paul by dilution. No doubt this was an influencing factor in the location of these industries.

In 1914, however, the Twin City Lock and Dam was built. This created a large quiescent pool which rapidly became offensive due to its septic condition and to floating sludge solids. It became apparent that the Twin Cities must do something about the sewage which emptied into this pool; but before plans could be made for corrective measures the federal Government came out with a new River and Harbors program. This program was the "Nine Foot Channel Project" which would make possible large barge traffic on the Mississippi, up to St. Anthony Falls.

To create the 9-ft. channel required for this improvement below the Twin City Lock and Dam and through the cities of St. Paul and South St. Paul, another lock and dam had to be built about 30 miles below the Twin City dam. This dam is now known as Hastings dam.

When the 9-ft. channel project was announced it was obvious that on its completion the Twin Cities and South St. Paul would have two septic pools instead of the one previously mentioned. Accordingly, interested parties such as the Minnesota Public Health Department, the Metropolitan Drainage Commission, and the South St. Paul engineers carried out extensive studies to determine what should be done to eliminate the pollution of the Mississippi. These studies showed that (1) it was advisable for the Twin Cities and South St. Paul to treat their wastes (this was upheld by the Minnesota State Legislature and in 1933 a law was passed making it mandatory for the Metropolitan area to treat all its sewage and industrial waste), (2) the cities of St. Paul and Minneapolis should build a sewage treatment plant, and (3) the city of South St. Paul should build a sewage treatment plant. With regard to the South St. Paul sewage treatment plant, it was decided that primary treatment would be adequate for some years to come.

On completion of these preliminary studies the city of South St. Paul hired the consulting engineering firm of Consoer, Townsend and Associates, of Chicago, Illinois, to design and supervise construction of a plant. The construction work on the plant and the intercepting sewer was carried out by the Okes Construction Company of St. Paul. The plant was built at a cost

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of $945,500; the cost of the intercepting sewer was $152,000.

Sewage was turned into the South St. Paul plant on the 15th of July, 1940 and, except for a few interruptions due to changes and breaks in the main interceptor, the plant has been in continuous service ever since.

Description of the Plant

The plant was designed to take care of a 10-m.g.d. flow. The main units are: screening units, grit chambers and roughing tanks, grease removal units, mechanical flocculation tanks, primary sedimentation tanks, primary trickling filters, and final sedimentation tanks.

The sewage enters the plant from the main interceptor at a ground level depth of 21 ft., which is 18 ft. below the high water level of the Mississippi. The fact that the main interceptor is several feet below the high water level of the Mississippi River causes considerable difficulty in the efficient operation of the plant and the maintenance of the main interceptor. Problems associated with this condition will be discussed later.

Screening Units

The screening units consist of two 7.5-m.g.d. comminutors and a 1-in. hand cleaned bar screen. The flow is controlled by gates so that all three or only one screening unit can be used at a time. After passing through the screens the sewage drops into wet well No. 1, from where it is pumped to the grit chambers and roughing settling tanks.

Grit Chambers and Roughing Settling Tanks

Originally the grit chambers were constructed as 3 separate tanks each 10½ ft. wide by 110 ft. long with a water depth of 8 feet. This gave a total capacity sufficient for a 30-min. detention period at a 10-m.g.d. flow. Each tank was equipped with its own straight-line "Link Belt" sludge and grease conveyor and a sludge suction line.

Experience soon proved that the sludge collected in these tanks could not be pumped either by use of centrifugal or displacement sludge pumps. After pumping a few hours during the killing time at the packing plants, the sludge lines from the grit chambers would plug, due to the matting effect of the straw and hay in the paunch manure. As soon as the sludge lines were plugged the entire plant had to be bypassed. This would continue for several hours until the grit chambers could be drained and cleaned manually. To solve this problem Consoer, Townsend and Associates and the Yeoman Brothers Company designed and built a conveyor and compressed air ejector which was able to handle this sludge.

The effluent of the grit chambers can flow by gravity either through the grease removal units and then to the mechanical flocculation units or directly to the flocculation tanks.

Grease Removal Units

The grease removal units are a pair of tanks 10½ ft. wide by 42 ft. long with an 8-ft. liquid depth. Sewage enters these tanks at one end, flows partially down the tank and over a 45° slope wooden baffle which extends nearly to the bottom of the tank and the center wall adjoining each tank. Actually, this forms two distinct parts in each tank, the V-shaped central space being quiescent while the outer area of the tank is used for an aeration chamber.

After entering the quiescent space the sewage flows under an adjustable weir at the end of the tank and then by gravity to the flocculation units. From time to time, depending on the accumulation of grease, the tank is skimmed by raising flood gates at the end of the tank. This floats the grease into the large U-shaped weir trough in the center of the tank.

This unit has not been used much for four reasons: (1) it was discovered that the introduction of aeration at the influent end of the grit chambers made these tanks effective grease removal units as well as grit chambers; (2) the short 6-min. retention, during peak flows, in the grease removal units was not enough to allow all the aerated grease to rise to the surface. Instead, the grease was carried over into the mechanical flocculators where it floated to the surafce and, due to the lack of a skimming mechanism, had to be removed manually; (3) in both the quiescent area and, to a lesser extent, in the aeration section of the tank, solids settled out. Since this was not anticipated, plans for the removal of these solids were not included in the original design. Thus it became necessary to bypass the unit and clean it manually each week, sometimes more often; (4) the cost of operating and maintaining the two rotary air compressors was no small item in discouraging the use of these units.

Mechanical Flocculation Unit

This unit consists of 3 flocculation tanks each 33 ft. wide by 55 ft. long with a liquid depth of 8 feet. This is sufficient volume when all tanks are in use to provide a 45-min. detention period on a 10-m.g.d. flow.

Due to the high content of suspended material in packing house wastes these units have proven very effective in the formation of conglomerate masses of sufficient size to settle readily in the primary sedimentation tanks. After 45 min., at 10-m.g.d. flow, in the flocculation tanks, the sewage flows through a baffled wall into the primary sedimentation tanks. There is one sedimentation tank for each flocculation unit.

Primary Sedimentation Tanks

Each of the 3 primary sedimentation tanks is 33 ft. wide and 110 ft. long with a water depth of 8 feet. Each tank is equipped with a pair of "Link-Belt" straight-line sludge and grease conveyors and has 180 ft. of effluent weir. At a 10-m.g.d. rate, the overflow rate for the effluent weirs is 19,000 gal. per ft. per day. The settling rate at a 10-m.g.d. rate is 920 gal. per sq. ft. of tank area, with a detention period of 1½ hours. The flocculation units and the primray sedimentation tanks are very efficient when compared to similar treatment of ordinary domestic sewage. Removal of B.O.D. in these units during killing days at the packing plants some years exceeds 340 p.p.m. (see operating data). The effluent of the primary sedimentation tanks flows by gravity to wet well No. 2 and from there it is pumped to the primary filters.

During peak flows all in excess of the 10-m.g.d rate is pumped to a one million gallon equalization tank. This partly treated stored sewage is bled back to the raw sewage during the night. At certain times, such as during spring floods, all flow in excess of 10 m.g.d. is pumped directly to the outfall sewer from wet well No. 2.

Trickling Filters

The present plant has 6 large, circular primary trickling filters, each 113 ft. in diameter with an average rock depth of 6 feet. Since over 90 per cent of the flow is packinghouse waste, heavy loadings on the filters were anticipated. Operating experience has shown that the 3 year average B.O.D. of the primary effluent going on the filters, during killing days at the packing plants, was 550 p.p.m. Designing engineers anticipated that these high loadings might cause ponding; therefore each filter was equipped with backwash facilities and with air lines at the bottoms for agitation of the wash water during backwashing.

The filters are not equipped with dosing tanks. Primary effluent is pumped directly to the PFT rotary distributors.

Before explaining in more detail how the backwash system operates, it may be of general interest to digress and point out that these filters are not housed and that during the past seven winters of operation none of the filters has frozen. It is true that during heavy winter wind storms ice collects on the distributor guide cables and on the filter walls. The icing of the guide cables never becomes serious for the ice is broken off by hitting the sharp rocks or parts of the drainage flume before it has a chance to stop the rotation of the distributors or to build up enough to be detrimental in any way.

It was discovered that the icing of the filter walls could be almost completely eliminated by raising the hinged diffused plates on the outside nozzles, allowing the sewage to flow in a steady stream rather than a spray. Several plants in this area have found that filter buildings have deteriorated to a point where complete reconstruction is necessary after less than 10 years of operation. Operation of the South St. Paul plant has indicated that plants having reasonably constant flow, or plants with equalizing tanks, do not need to cover trickling filters in order to keep them operative during the winter if located where climatic conditions are similar to or less severe than those in Minnesota.

Since backwashing of trickling filters is not a common procedure, it may be worthwhile to discuss this process in more detail. For backwashing, 450,000 gal. of plant effluent is used for each filter. The wash-water is not pumped directly into the filters but instead is pumped to an elevated storage tank of 475,000 gal. capacity.

During backwashing the elevated tank is allowed to empty very rapidly through a 48-in. concrete conduit. The flow up through the filters is at the rate of 15,000 gal. per min. with a hydrostatic pressure at the base of the filter of 6.3 to 4.7 pounds. To aid in backwashing, a grid of air lines with orifices spaced 18 in. from center to center was placed 6 in. above the bottom of the filter rock. To compress air for this aeration system a blower delivering 6,500 cu. ft. per min. is used. It delivers 3 lb. pressure at the discharge of blower.

Experience has proven that: (1) the elevated tank is not as high as it should be to get the best results with the volume of water used. An additional 3 or 4 lb. of hydrostatic pressure would greatly improve the backwash process. An increase of 6 in. in elevation of the South St. Paul back-wash tank, which added a few thousand gallons of water and approximately ¼ lb. of water pressure, considerably increased the efficiency; (2) more air at greater pressure would be desirable. The increased pressure would help prevent the clogging of the orifices and a larger quantity of air would produce greater agitation of the wash water. After passing up through the filters the backwash water is drained into a ½-mil. gal. storage tank from which it is bled back to the raw sewage during the low night flow. The effluent from the trickling filters flows by gravity to the final sedimentation tanks.

Intermediate Final Sedimentation Tanks

The intermediate sedimentation tanks, which function as final settling tanks as the plant is now built, are the same size as the primary sedimentation tanks and provide a retention period of 1.5 hr. at 10-m.g.d. flow. These tanks are also equipped with "Link Belt" straight-line sludge and grease removal equipment.

During average and low river stages the effluent from these tanks flows by gravity directly to the river through the outfall sewer. During flood stages of the river the effluent flows by gravity into wet well No. 3 from which it is pumped to the river. Thus during high river stages the entire flow of the plant has to be pumped three times.

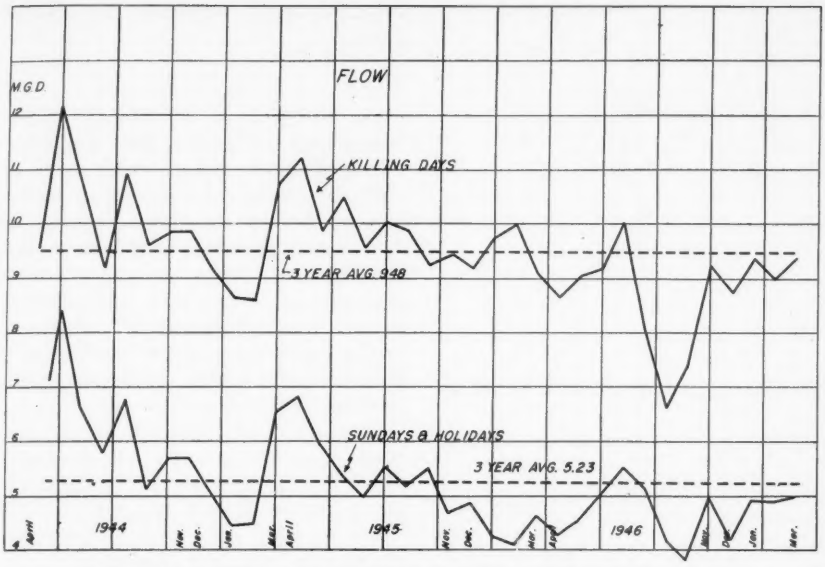

FIGURE 1.—Plant flow for killing days and Sundays and holidays.

This pumping adds considerably to the cost of treatment but could not be avoided due to the relative elevations of intercepting sewer and treatment plant.

Laboratory and Operating Data

Sewage Flow

The average sewage flow for killing days (killing days are the days the packing plants are killing, usually week days) during the past three years was 9,475,000 gal. per day (see Figure 1). On Sundays and holidays it was only 5,230,000 gal. per day. Weir studies of various parts of the city indicate that better than 90 per cent of the sewage flow on week days is industrial waste from Armour, Swift, and the stockyards, the city domestic flow contributing less than 10 per cent of the total flow.

Since the flow is mostly industrial waste, large daily as well as hourly variations occur. Figure 2 illustrates graphically to what extent the flow varies, both hourly and daily. It will be noted by following the heavy dark line, that during killing days the flow rate varied from about 5 m.g.d to more than 17 m.g.d. Flow records show that the high Sunday flow seldom exceeds the low flow on killing days. This is substantiated by Figure 2 which was drafted from data collected in October, 1940, when the high Sunday flow did not quite reach the low flow of killing days.

Sewage Strength

Even as large as these flow variations are, they are not as large as the variations in the strength of the sewage. The dotted line of Figure 2 is an hourly graph of what has been called the "settleable solids index." It is obtained by multiplying the settleable solids in ml. per liter by the rate of flow in m.g.d., divided by the average daily flow in m.g.d.

$$\text{Settleable solids index} = \frac{\text{ml. of settleable solids per liter} \times \text{rate of flow in m.g.d.}}{\text{average daily flow in m.g.d.}}$$

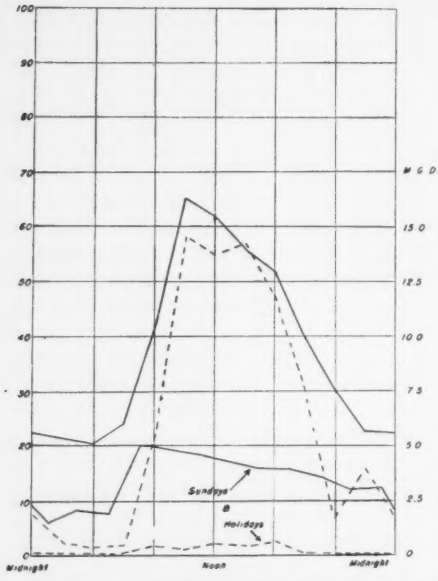

FIGURE 2.—Plant flow in m.g. for typical killing day (October, 1940). Dotted line equals ml. of settleable solids per liter times rate of flow in m.g.d., divided by average daily flow in m.g.d.

From the dotted line in Figure 2 it can be observed that the hourly variation in amounts of solids reaching the plant on killing days may be as great as 25 times the minimum hourly amount for the day, and that the maximum hourly amounts received on killing days may be as much as 100 times greater than the minimum hourly amounts received on Sundays.

These high variations in solids loading produce many difficult problems in sludge handling. Because of this, the grit chambers had to be equipped with drag conveyors as well as facilities for pumping the night and early morning sludge on Sundays and holidays.

From an examination of Figure 1, it will be noted that flow trends at the South St. Paul plant are encouraging, for during the last three years there has been a constant decrease in flow, indicating that the plant facilities, except for the disposal of sludge, can be expected to be adequate for several years.

B.O.D.

On killing days, the B.O.D. of the raw sewage for the last three years has averaged 1,009 p.p.m., with a peak monthly average of 1,710 p.p.m. and a low of 584 p.p.m. (see Figure 3). The large fluctuations in B.O.D. during the last year were caused by OPA activities in the packing and marketing of meat. Normally one could expect a yearly curve much like that produced in 1944–1945, with the peak loading in the winter.

The B.O.D. of the plant effluent for week days (Figure 3) has averaged 236.8 p.p.m. This represents an overall reduction of 76.5 per cent with a removal of 772 p.p.m., when figured on the basis of the flow. Using only killing days, the average daily removal of B.O.D. was 60,700 pounds. This removal compares very favorably with that of the large 145 m.g.d. Buffalo, New York plant which serves an estimated population of 600,000 persons, and removes about 56,500 lb. of B.O.D. per day. The South St. Paul treatment plant's average daily B.O.D. removal is nearly half that of North Side Works of the Sanitary District of Chicago and on a few heavy days may nearly equal, and possibly even exceed, that of the big North Side Works.

With these high removals the average cost per ton of B.O.D. removed was low during 1944–1945. The cost at South St. Paul was $5.20 per ton of B.O.D. compared with the $24.04 average cost at 18 of the larger sewage treatment plants in the United States (Table I).

It is not claimed that these spectacular results are due to efficiency of operation, but rather to the type of raw sewage entering the plant. Because of the heavy loading of paunch manure, it is possible to remove 21.0 per cent of the raw sewage B.O.D. in the grit chambers alone, and an additional

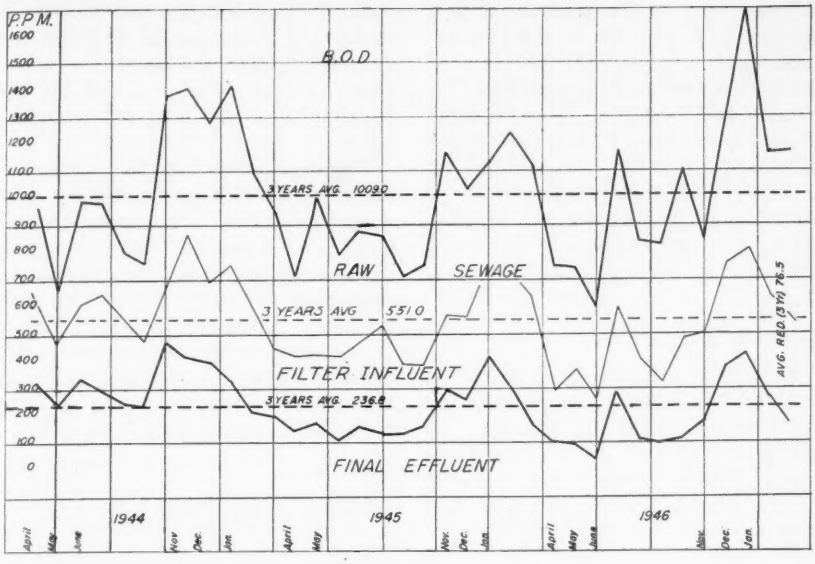

FIGURE 3.—B.O.D. of raw sewage, filter influent and final effluent.

TABLE I.—Cost Data For 18 Sewage Treatment Plants

Location	Year	Ave. Flow (m.g.d.)	Cost per M.G.D. ($)	Cost per Ton Dry Solids Removed ($)	Cost per Ton B.O.D. ($)
Toledo, Ohio	1944	36.80	6.92	—	15.45
Pasadena, Calif.	1944–45	11.00	21.38	—	21.90
Ann Arbor, Mich.	1944	4.80	20.11	22.60	23.30
Marshalltown, Iowa	1944–45	3.05	28.57	14.95	21.60
Green Bay, Wis.	1944–45	7.67	10.85	20.95	42.40
Gary, Ind.	1944	18.83	11.64	9.05	16.48
Buffalo, N. Y.	1944	145.00	8.40	41.50	54.50
Belleville, Ill.	1944–45	3.15	26.50	—	21.06
Hartford, Conn.	1943–44	21.90	10.71	63.25	—
New Britain, Conn.	1944–45	9.49	19.63	27.75	35.60
Aurora, Ill.	1944	6.62	14.08	22.10	32.75
Elizabeth, N. J.	1944	37.17	9.31	—	22.60
Urbana-Champaign, Ill.	1944–45	3.45	18.68	—	19.58
Indianapolis, Ind.	1944	63.26	9.81	—	14.30
Richmond, Ind.	1943	5.00	9.72	—	16.60
Mpls.-St. Paul, Minn.	1945	118.60	7.42	7.63	24.60
Marion, Ind.	1944	4.32	17.91	—	28.26
Winnipeg, Man.	1944	20.30	8.95	10.80	22.80
So. St. Paul, Minn.[1]	1944–45	9.48	14.26	3.75	5.20
So. St. Paul, Minn.[2]	1944–45		9.10	2.40	3.30
Av. of 18 plants, not including So. St. Paul			14.43	—	24.04
Av. of 10 plants, not including So. St. Paul			—	30.06	—

[1] Gross cost of treatment. [2] Net cost after deducting value of recovered grease sold.

24.5 per cent in the mechanical flocculators and primary settling tanks. Thus, approximately 59.5 per cent of the total reduction is accomplished by primary sedimentation. The trickling filters remove more B.O.D. than might be expected, for the sewage going on the filters has an average B.O.D. of 551.0 p.p.m. (See Figure 3). Of this, 314.0 p.p.m. are removed by the filters and the final settling tanks, which is 57 per cent of the applied B.O.D.

Settleable Solids

As might well be expected of a plant with trickling filters, practically all the settleable solids are removed. Of the average 11.4 ml. per l. of settleable solids, 11.18 ml. per l. are removed. This represents an overall removal of 98.0 per cent (See Figure 4).

Suspended Solids

The suspended solids removal has also been satisfactory, for of the 781 p.p.m. of suspended solids entering the plant, 730 p.p.m. were removed. This gave an overall removal of 93.5 per cent. Of this, 50.2 per cent is removed by the grit chambers and 36.3 per cent by the primary sedimentation tanks, with 7.0 per cent removed by the trickling filter and final sedimentation tanks.

The high percentage of removal by the grit chambers and primary sedimentation tanks is attributed to the nature of the sewage. The raw sewage has enough heavy organic material in suspension so that when it becomes quiescent in the grit chambers and in the primary sedimentation tanks this material quickly settles out, removing the suspended solids nearly as effectively as a chemically produced floc.

Total Solids

On killing days, during the last three years the total solids of the raw sewage averaged 2,800 p.p.m. Of this, 1,049 p.p.m. was removed by the sewage plant (Figure 5). This appears to be a low percentage of removal. This is because the well water used by the industries contains nearly 1,000 p.p.m. total solids as pumped from the wells

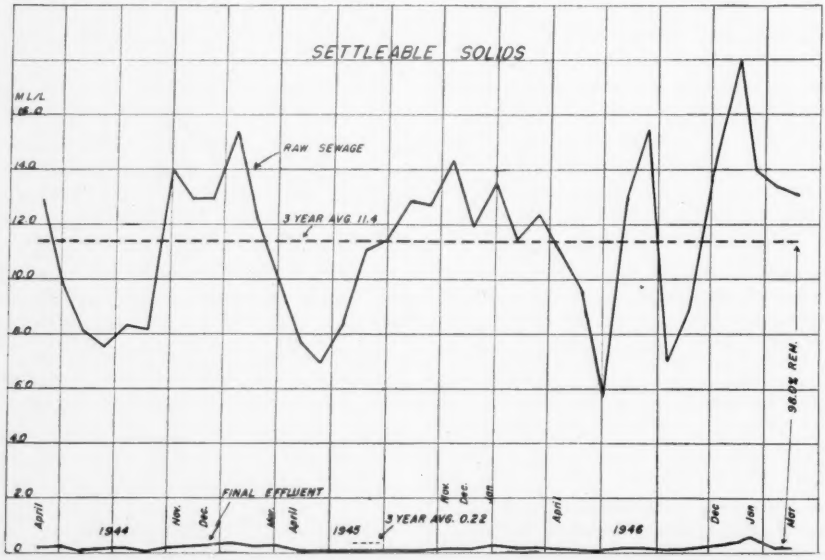

FIGURE 4.—Settleable solids content of raw sewage and final effluent.

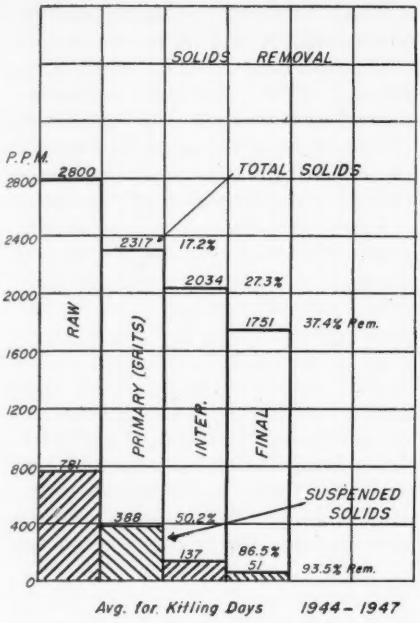

FIGURE 5.—Average solids removal through plant for killing days, 1944–1947.

and because a large part of the salt and other pickling ingredients used by the packing plants eventually reaches the sewage treatment plant and is not removed by the treatment process. Analysis for non-volatile solids revealed that there were 1,687 p.p.m. in the raw sewage and 1,601 p.p.m. in the plant effluent, which shows that only a small part of the non-volatile solids are removed by the plant. Annually, however, 12,887 tons of solids are removed.

Since the South St. Paul plant is relatively small and our operating costs are low, the cost per dry ton of total solids removed is only about 12.5 per cent of the average cost at 10 of the larger plants in this country. The cost at South St. Paul in 1944–1945 was $3.75 per ton as compared to an average of $30.06 for the 10 plants studied (Table I).

Grease Removal

At most plants grease removal is just another headache, but at the South St. Paul plant it is a source of considerable revenue. During the last three years the average annual income from the sale of grease has been $14,467. In 1940–1941 and 1942, however, the flow of grease to the plant was much heavier and also of much better quality.

At times in the winter of 1941 and 1942, as much as 60 barrels of 30 per cent grease was skimmed from the grit chambers daily. But as soon as the packing plants learned that tremendous quantities of grease were getting away from them they redesigned and increased the number of grease removal units and catch basins. These devices effectively reduced the flow of grease to the treatment plant. This is another case where a sewage treatment plant has gone a long way toward paying for its operation by pointing out to the waste producers losses that could be avoided.

When computing the cost per m.g. of sewage treated, tons of solids removed, and tons B.O.D. removed, the revenue from the grease was not included. Had it been included the cost of treatment per m.g. would be $9.10, the cost per ton of solids removed would be $2.40, and the cost per ton of B.O.D. removed would be $3.30.

Sludge Disposal

All sludge is lagooned. Due to the large amount produced annually all available space is rapidly being filled. Effort has been made to dispose of the sludge by promoting its use as fertilizer and several hundred loads have been hauled away for that purpose. The amount thus disposed of is only a small fraction of the total produced annually. At present, the lagoons contain 50,000 tons (dry weight) of sludge. About 10,000 tons is being added per year.

Operation—Administration

The operation of the plant is under the direction of a three-man Sewage Disposal Commission, created by ordinance and appointed by the City Council. The commission members are appointed, with one re-appointment yearly. An annual operating budget is established, 90 per cent of which is paid by the industries served and the remaining 10 per cent by the city. This is in accordance with a 15 year agreement between the industries and the city.

The city's 10 per cent is raised by a sewer rental charge, which originally was set at 30 per cent of the amount of the individual water bill for the quarter ending March 31st of the previous year. This 30 per cent has since been reduced to a 15 per cent charge.

Plant operating personnel consists of an operator and helper on each of three shifts, one relief man, three laborers on the day shift, a chemist, and a superintendent. Salaries at the present time are: operators—$257.50 per month; helpers—$211.50 per month; and laborers—$1.05 per hour.

Every precaution is taken to safeguard the health and life of the employees. All are inoculated at three-year intervals against typhoid and para-typhoid A and B. Safety equipment is provided in the nature of a carbon monoxide detector, a hydrogen sulfide detector, a "Wolf" safety lamp for detection of methane gas and warning of oxygen deficiency, two all-purpose gas masks, one chlorine gas mask, safety helmets, dust respirators, goggles, and complete first aid equipment.

BARK FROM THE DAILY LOG

By W. W. Mathews

Superintendent, Gary (Indiana) Sanitary District

November 1—After being submerged with 9.7 in. of rain in October, November starts off with a half-inch rain which seemed to stir up all the sand in the sewer system. As a result the north grit chamber became overloaded, the grit collectors shut down, and considerable sand carried over into the primary clarifiers, plugging the sludge hoppers and even clogging the raw sludge suction lines. What a little rain can do!

November 2—Flushing the raw sludge lines occupied most of the day. For this reason, practically no sludge was pumped to digesters. The north grit chamber was drained, the grit shoveled into a dump truck and hauled away. This wasn't quite as convenient as mechanical removal. Finally got the grit chamber back in service but the raw sludge lines and primary hoppers are not yet cleared of all sand.

November 3—Professor Galligan and 28 engineering students from Iowa State College visited the plant today. Gas production is low and the motor driven pumps are in service. The outfalls are causing some trouble. One connection to the interceptor was found to be stopped with sand. An outfall flood gate was found partly open, with debris which was wedged under it during the rain storm preventing proper closure. A float control at another regulator was jammed. Just one d—— thing after another!

November 4—Rain again! Not too much today, however, but the ground water is so high from last month's rains that infiltration is up, pumpage high, and gas production down. These rains cost us money!

November 6—Record day, today! We pumped almost 41 m.g. to the plant, the largest flow in plant history.

Otherwise, today's was just another rain storm. The grit chambers are functioning properly. Also the outfalls and regulators. And at last all the sand has been flushed and pumped from raw sludge lines so that the digesters are getting sludge again, such as it is. Sludge volatile percentage is down to 40.

November 7—Snow and cold for variety. Recirculation was started in all primary digesters with the hope that it will put a little life into the digestion process. We need a little more digester action!

November 10—The flow seems to be getting back to normal. Over 22 m.g. was pumped during each of the last two days. Sand is still causing intermittent trouble in the raw sludge lines. Another regulator float was found to be jammed.

November 11—The low flows of the last two days apparently were not indicative of the actual sewage flow. When the jammed float of the regulator was released, the flow went to 29.77 m.g. today. The effect of the high ground-water level and surface runoff is still evident. The B.O.D. of the raw sewage is down to 20 p.p.m. Raw sludge volatile content is down to 36.5 per cent.

November 13—Cleaning of the diffuser tubes in No. 5 aerator was started today. Gas production is up so that operation of pumps and air compressors with sludge gas could be resumed. Whether this gas increase is due to the recirculation of several days back, delayed digestion, or better sludge, is not apparent. Since the first part of October the graph for pumpage looks like a condensed profile of the Rocky Mountains going up, while that for the gas production looks the same, only in a reverse direction.

November 24—All empty aerators were filled about two-thirds full to protect diffuser tubes against freezing. The return sludge lines from the secondary clarifiers were cleaned. A cold snap may drop in on us any night.

November 27—The annual meeting of the Indiana Sewage Works Association was held today at Indianapolis. Excellent papers were read on "Selling Sewage Sludge," "Maintenance of Mechanical Equipment," and "Sewage Treatment as a Vocation." In regard to the latter, at times it would appear that there must be an easier way of making a living!

December 1—With 3.04 in. of rain in November added to October's heavy rainfall, pumpages and treatment results varied widely during the month. Average daily pumpages ranged from 18.10 to 40.74 m.g. Suspended solids in the final effluent jumped from 1 to 31 p.p.m., while the B.O.D. varied from 2.4 to 15.5 p.p.m. Although it might appear that the above variations are not excessive, they are unusual in that they followed no pattern. The best results sometimes occurred on days when the solids and B.O.D. loads were the greatest, with the poorer results occurring with very light loadings.

The reason for this, as we see it here, is the wide variation in pumpage rates (not pumpage totals), which varied some days from as low as 17 m.g.d. to almost 60 m.g.d. Even with the rate to the secondary treatment process controlled to keep the solids concentration in the aerators and the flow as near uniform as possible, dilution from storm water runoff caused the B.O.D. of the raw sewage to vary from 20 to 317 p.p.m. and the suspended solids from 42 to 726 p.p.m. To exaggerate slightly, these fluctuations might be stated as ranging from no load to full load within 24 hours, which is not advantageous for producing optimum results with the activated sludge process.

December 2—Number 5 gas engine down for an overhaul after 7,144 hr. service. When cleaning the diffusion tubes of No. 4 aerator, mineral wool

was found in most of the tubes. We need no insulation there!

December 5—Inspection of bearings and liners on No. 5 gas engine showed little wear. All liners were found to be smooth and shining. This was a welcome discovery.

December 6—The transfer pipes in the multi-digestion system are acting up from too much sand. Two maintenance men worked on them until midnight. When these transfer pipes are not working the results are immediate and objectionable! The corresponding primary digesters overflow unless checked promptly.

December 10—Pumpage has been decreasing for the past two weeks indicating a drop in ground-water level, with less infiltration. Controlling solids in the mixed liquor is much simpler with the flow stabilizing around 20 to 22 m.g.d. than with it varying up to 30 m.g.d.

December 14—A sharp drop in today's flow, from 20.3 m.g.d. to 10.4 m.g.d., indicated that something had happened. A quick check of all outfalls showed that a cable had broken on one of the regulators causing all sewage at that location to discharge to the river. Following the cable repair, the flow came back to normal.

December 17—A new scheme for clearing a stopped raw sludge line was tried today. The main suction header for the four primary clarifiers terminates in a cross, flanged on the opening opposite the run of the header. When this flange was removed the line was found to be stopped with sand and sludge. In blowing out the line the mixture was allowed to drop onto the floor of the pipe gallery. This made a mess but it affords quick line clearance. Some improvement to cleaning the floor with shovels and brooms will have to be worked out later!

December 18—Flushing of the raw sludge lines yesterday permitted normal sludge pumping to the digesters today and the bugs promptly responded with more gas. If fed, they will really produce!

December 23—Bill Lauer of the Dorr Company was here today, checking on equipment. Fortunately, Bill is a genial guy, as a rule. Pays to keep him that way too, for he used to be a sparring partner for a heavy weight champion. One of those cold winter rains came down last night and over 30 m.g. is running through the plant today. This was a flash storm and apparently has had little, if any, effect on the treatment process.

December 27—After a 10° drop, the temperature today leveled off to about 30° F. The freeze reduced the flow considerably. The first icy pavements of the winter came with the temperature drop but the plant benefited from the decreased flow.

December 31—After several days of freezing weather the flow is now just under 20 m.g.d. and the plant is coasting at this rate. December, taken as a whole, was a good winter month for the sewage treatment process with less than one inch of rainfall, receding ground water, and gas production accelerating the latter half of the month. We end the first calendar year of operation in good shape with nothing in particular requiring special attention. The plant functioned properly with the final effluent carrying 8.2 p.p.m. of suspended solids and 8.8 p.p.m. of 5-day B.O.D. (annual average), with corresponding reductions of 96.1 and 94.3 per cent. Naturally, there will be many problems to solve during the coming year.

January 1—Happy New Year! The temperature rose to above freezing last night, so we are starting the New Year off with a little rain. Not enough to worry about—yet!

A visual record of operating statistics has been of great assistance in noting trends in the treatment process. It should prove helpful for any type plant. A ruled sheet covering the year by month and days, with the ruled

portion about 10 by 14½ in., is used and can be obtained from any supplier of engineering drawing materials. On this flow sheet, reading from the top to bottom, is plotted: total lb. of solids pumped to digesters; total lb. of volatile solids pumped to digesters; daily gas production; gal. of spent pickling liquor discharged to sewers (this is shown in red with length of line indicating 2,000, 3,000 or 6,000 gal. or a combination of the totals); pH of raw sewage and mixed liquors; sewage flow in m.g.d.; and daily rainfall in inches.

On a second sheet are plotted: blower pressure in p.s.i.; cu. ft. of air per gal. of sewage; D.O. of the final effluent; D.O. at effluent end of the aeration tanks; per cent reduction in B.O.D.; per cent removal of suspended solids; B.O.D. of the raw, clarified, and final effluent.

A third sheet has on it: maximum and minimum daily temperatures; sludge index; mixed liquor solids, in p.p.m.; return sludge solids, in p.p.m.; and the per cent volatile solids in the mixed liquor, clarified sewage, raw sewage, and raw sludge.

These sheets are mounted in cardboard folders to keep them clean and to protect them from damage since they are used at least once a day and sometimes several times each day. They can be lined up for convenience in checking "across the board." Any trend or variation that may effect the treatment process is instantly apparent.

In addition to the plotted record, two control sheets are made up each month on 8½ by 11 in. computation paper. These are in addition to the log sheets and the forms on which reports are made to the State Board of Health. These control sheets contain all the data from which the graphs are plotted and additional information about the return sludge.

The plotted records plus the control sheets give a complete picture of the treatment plant operation for any day or for the year, up to the current date. Lest anyone think that these records require considerable time to maintain, be assured that the most time is taken in laying out the sheets for the curves and in lettering the various side headings. Not over 5 min. a day is required to keep the graphs up to date. The control sheets are filled in by the chemist in the laboratory as he completes the daily log sheets. These control sheet notations probably do not take over 5 min. of time. At the end of each month average lines are drawn in for those items which are watched closely and these serve to indicate seasonal trends.

A daily inspection of the various tanks and samples along with a study of the graphs and control sheets has been of material assistance in controlling our plant operation.

January 2—On the 12 M. to 8 A.M. shift grit came into the plant at such a high rate that the grit collector shear pin was broken and the grit chamber filled about half full of grit. All available labor was used in shoveling out grit until the collectors could be started again. Back to normal at 10.45 A.M.

January 4—The temperature dropped to 3° below zero this morning. From yesterday's 155, the sludge index jumped to 315. No apparent reason could be found for this marked change. The flow, suspended solids, and air per gal. were all normal as compared to previous days. No bulking was noted in the final tank. The plant effluent contained only 4 p.p.m. of suspended solids and 3 p.p.m. of B.O.D. The D.O. at end of the aeration tanks was 4.6 p.p.m., and 7.4 p.p.m. in the plant effluent. Whatever has caused the high sludge index hasn't hurt the plant operation—yet!

January 5—The sludge index dropped back to a normal 169 today, and the

final effluent continued low in solids and B.O.D. Temperature low of 8° below zero last night!

January 6—The cold wave is really here! Water pipes in laboratory froze this morning as result of the 9° below temperature. The weather hasn't hurt the treatment process but it is hard on the outside operators.

January 8—After two nights of sub-zero weather, the sludge index really soared today, reaching 410. Again, all other steps in the treatment process show normal conditions. Nothing like this last winter. A large question mark is indicated!

January 17—Everything has been quiet for the past few days but today a small fountain appeared in the lawn near the aeration house. Excavation uncovered a loose coupling on a flushing line, which was easily and quickly fixed.

January 31—Rain changing to snow at 2:00 A.M. A heavy runoff, with the three sewage pumps on almost all night pumping at a 55 m.g.d. rate! Total for day, 31.59 m.g.

February 1—January was a very satisfactory month with only 1.48 in. of precipitation so that the pumpage averaged 18.22 m.g.d. Following the onset of cold weather, the sludge index never was below 290 and reached a high of 583 on the 24th. The daily average, 8th to 31st inclusive, was 429. Treatment results did not reflect the high index, for the monthly averages for susended solids and B.O.D. in the final effluent were below 10 p.p.m. A careful study of all factors affecting the treatment process showed that, with the exception of the sludge index, these varied less than in any previous month. With this fact established it would appear that the low temperature prevailing during the month was the contributing factor. This problem calls for further study.

February 8—The past four days demonstrate how floods occur. Starting with the frozen ground partly covered with snow and a 0.18-in rain on February 4th, the daily precipitation for the next three days was 0.31, 0.82, and 1.21 inches. As a result sewers were surcharged and basements flooded. In some places streets were flooded to such an extent that the water ran into homes through the basement windows, putting out furnace fires. One street in particular was so completely submerged that the sewer department removed the manhole covers to get rid of the water as quickly as possible.

With a combined sewer completely filled, the regulators diverted so much of the storm flow to the river that the daily pumpage at the plant was not as great as during moderate storms. The type of storm that raises the pumpage rate the most is a long, sustained, light rain that fills all of the sewers about half full. The flow is not great enough to cause the regulators to close and all the water that reaches the main interceptors has to be pumped.

On the evening of the 7th when things seemed to be getting under control, grit began to pour into the plant. The grit remover again was overloaded and put out of commission. Called out the crew to shovel grit and since it was Saturday no one was particularly happy about it!

February 10—As an aftermath of the flood, the drainage ditch outlet for the small trickling filter plant serving Miller community, a suburb of Gary, rose, completely submerging the secondary clarifier and flooding the main sewer so that it was necessary to shut down the plant. All the low land in this area is now covered with water. The rain and flood water of the last few days have started the same old operation cycle again—the light volatile solids are diverted to the river and our gas production takes its usual nose dive.

February 13—The plant operator called at 9:30 P.M. about the gas engines, which were running unevenly.

Out to the plant with our chief operator. We found that the gas header, scrubber, and drip pockets had not been drained completely and the gas could not flow in usual volume to the engines. After draining the equipment properly, everything again ran smoothly. When a job isn't done right, trouble always follows!

February 20—Because of low gas production, we rolled out the old standby steam road roller and started steam into digester No. 2. It's been just about a year since it was used for the same purpose. Does this (1941) predate Rawn's experiments with steam for heating digesters? An old steam road roller is mighty handy to have around sometimes!

February 26—Snow flurries and a 22° above temperature. The return sludge pipe from No. 7 secondary clarifier clogged today and it was a cold job getting this tank back into service. Not so much the work as the wind and snow.

March 1—February was one of those months. Not from the treatment standpoint, for this was quite satisfactory. Sludge indices dropped from the high level of the previous month. There were only six days when the index was above 300. Complaints about flooded basements were numerous and these wear one down when they are being reported from morning until night. The Sanitary District has nothing to do with local sewers but when people are desperate and do not know where to call, they just will call the plant. Well, perhaps March will be more peaceful!

SEWER MAINTENANCE IN SMALL CITIES*

By Don C. Davis

City Engineer and Manager of Public Works, Turlock, Calif.

In the maintenance and operation of small city sewer systems it is necessary first to take a critical look at the municipal organization, find its faults, correct as many as possible, and make the best of those which cannot be controlled.

In the first place, the departmental head is usually a man who, like the country doctor, must qualify as a general practitioner and who must be competent to supervise not only sewer maintenance but also plant operation, water supply and distribution, street repairs, and be the leaning post for all other departments in the city. In order to do this kind of a job well, a man must be a practical, walking encyclopedia, which is impossible. So occasionally something must be neglected and entirely too often that something might be the sewer system. When sewer maintenance is considered seriously, however, it is found to be a subject replete with many wonderful and interesting phases.

Sewer Cleaning Practices

The most obvious item of sewer maintenance is cleaning. In this, the first consideration must be—"when," even before the "how" of cleaning is decided. The character of sewage, the flatness of sewer grades, the condition of mains and laterals, and weather conditions are some of the things which dictate frequency of cleaning.

Generally speaking, in a good sewer system once-a-year cleaning is sufficient. Perhaps a good flushing is all that is necessary, but dragging with a coil or brush, or both, is more fre-

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quently indicated. If in the construction of sewers good practice was followed and if an adequate plumbing ordinance is well enforced, cleaning once a year is about all that should be needed.

Since the millennium probably will never arrive for the sewer maintenance man, he must contend with joints and cracks which encourage growth of roots inside of the sewers. At Turlock inflows of sand occur both through sewer joint and manhole cover openings, from inadequately policed wash racks, and from industries. Sludge deposits build up which almost invariably lead to odor complaints.

Maintenance records provide the only adequate answer for knowing when to clean sewers before complaints start arriving. How can the required frequency of cleaning be estimated unless the cleaning which has been necessary in the past is known? Each foreman can be furnished daily report forms and instructed to record the work done, the time and date, the conditions found and the material removed, and whether the cleaning was routine or in answer to a complaint. See to it that such reports are turned in daily, or confusion will result. Even in a small town the use of such records is advisable because all too many wrong diagnoses are made when foremen try to rely entirely on memory.

Intelligent use and periodical analysis of these reports will readily show where the bad spots of a sewer system are, will indicate what the trouble is, and, more often than not, will point out some indication of what to do to correct the trouble. Unless the maintenance costs of a given length of sewer pipe or a pump station are known, how can it be determined what expenditure will be justified to correct a given condition? No municipal accounting system is broad enough to give such detailed information. Only the sewer department can conveniently keep such records. Along with such reports a liberal use of city maps should be made upon which have been placed the sewer lines and other pertinent information.

Most sewer cleaning in small cities is a seasonal job, usually done in the spring and the fall, and usually during those periods when water and street work is not so pressing. At times there is a tendency to permit those municipal functions having physical plant which can be seen to take precedence over such unseen things as sewer lines. Since this attitude is particularly true of the elective officials, it is up to the sewer superintendent to get his work done before nuisances develop because of stoppages or bad odors. If the general public never has to realize the existence of the public sewer, then it can be assumed that the sewer superintendent has done a good maintenance job.

The man in the sewer should be taught to know his equipment, both what it can do and what its limitations are. Many sewer rods of all types have been broken and sewers have been dug up to retrieve lodged tools simply because the man in charge failed to instruct his men in the proper use of such tools.

One other point deserves mention. Just because a particular type of tool has been used for years with supposedly satisfactory results is no reason to be smug in the opinion that another type of tool might not do some of the work better. There are several cleaning tools on the market and it behooves the sewer superintendent to get the type or types best suited to his own city's peculiar requirements. When purchasing new tools and equipment, insist, as a condition of purchase, that a qualified operator instruct your own crew in their proper operation. Entirely too many salesmen make the sale of a piece of equipment and then let the purchaser worry about how to use it.

Control of Sewer Construction

In speaking of maintenance of sewers in the small city, it is desirable to

touch on sewer construction if the complete picture of maintenance is considered. Men from the larger communities may believe that construction has no place in maintenance programs but all small town maintenance men know better. Why? Because they not only maintain but also construct sewers, sometimes, unfortunately, in the same manner. When maintenance work is spotty and inadequate, construction is also carelessly performed. Fortunately, however, a good maintenance crew can usually do good construction work. Such things as good design and sound construction of sewer lines can lighten the burden of the maintenance man, but jobs not well conceived nor well executed can result in many hours of unnecessary maintenance work.

In Turlock municipal employees put in all minor sewer extensions as well as some other construction work, and usually do some of the larger jobs also. Generally when a big job comes along and the city fathers employ consultants, the local sewer superintendent usually still gets in on the job. Too many times after a sewer system or a major extension has been carefully designed, with due consideration taken for all the factors such as volume of flow, type of sewage, available slope, etc., a contract is awarded and an agreement made with the council for the employment of a local inspector. This local inspector frequently is a local employee or sometimes may be a local man highly trained by political experience. The job is then abandoned to said inspector. Not all consulting engineers are guilty of this practice but it has occurred many times, particularly in the very small cities where a city engineer is not regularly employed.

When a job is done by contract the quality of the work is as good as the contractor is willing to give. When it is done by the local maintenance chief or sewer superintendent the job is as good as he has time to devote to it. Often the same old sand-cement jointing material is used, and grades are established by eye, or at best by a carpenter's level. An inch or two seems close enough. If the local plumber is employed, he usually gets it further off than that.

What should be done about it? First, let the sewer superintendent consider the following:

1. *Type of Pipe.* The type of pipe most commonly used, of course, is salt-glazed vitrified clay, particularly in the small sizes. Unglazed sewer pipe is now being promoted as being satisfactory for normal usage. Sometimes spun cement or machine-made cement pipe is used. While economy is the keynote here, local experience will dictate the wisdom of using such pipe. Some communities which are fortunate in having a soft water supply can satisfactorily use cement pipe. Those cities with a hard water supply, however, particularly if it is high in sulfates, should play safe and use the clay pipe.

2. *Slopes.* In many cities, particularly those in the interior valleys of California, it is frequently impossible to get adequate grades sufficient to develop self-cleaning velocities without the necessity of installing lift stations. A long, flat sewer with low flow velocity can and generally will produce hydrogen sulfide, with resultant odor complaints which make frequent cleaning necessary. In the warmer parts of California this trouble is common and is most noticeable during the long, warm, summer evenings.

One of the toughest jobs the sewer man has, when it comes to deciding between lift stations and very flat slopes, is to convince the city officials that lift stations are not an unnecessary burden and, if well designed, are not particularly expensive to operate.

3. *Jointing Materials.* Sand-cement mortar joints laid in a 16-in. line in

1916 and recently uncovered by new construction work showed almost all joints to leak seriously. Since this line lies below the normal ground water level, the infiltration must have been considerable, particularly during periods of low flow. In those areas adjacent to trees, shrubs, alfalfa, and other plants, root trouble was prevalent in this line.

Another line constructed in 1928 with neat cement caulked into the joints showed very little leakage when uncovered except at those points where mechanical damage had resulted from soil movement. Root trouble was negligible except at these points.

Poured asphalt mineral-filler joints have a very good record but here again roots have been known to enter the joints, mostly where adherence was not sufficient between the jointing material and the vitrified clay. The only roots which have been reported as entering this type of joint material are those of the athel tree, a species native to the desert areas of California and Arizona.

The sulfur-base compounds are a rigid-type joint material having about the same qualities found in the neat cement joints.

The coal-tar and mineral-filler compounds are too recently developed to permit definite conclusions. It is understood that the biggest objection to their use is the higher heat required for handling.

In considering all available sewer jointing materials, no material has been found to be perfectly satisfactory. The best one to use probably is the one the maintenance men have become expert in placing. Sand-cement joints, however, should be ruled out regardless of the circumstances.

Sewers have been laid without any jointing material. In Turlock it is now necessary to relay an estimated 1,200 ft. of 8-in. vitrified clay pipe because some years ago a contractor was permitted to lay this line without bothering to install jointing material. It was reported that shortly after installation this line began to produce a remarkable amount of sand. This apparently did not bother anyone very much until recently when a rather large piece of pavement broke off and fell into a crater right after a loaded truck passed over.

Exploration of this crater showed that no jointing material whatever had been used although the pipe was in perfect condition. The soil is of a very sandy nature so the sand had been infiltrating through the joints for these many years. The relaying of this pipe at a cost of at least three times the original cost is apparently the only answer.

4. *Installation.* Never permit construction work to proceed without first having it laid out by a competent engineer or surveyor. Then check the work frequently to see that the engineer's grades are faithfully followed. If this appears to be an unnecessary precaution it is only because some small city construction crews have never been observed in operation.

Here again records are most necessary. It is advisable to have a surveyor locate the structures and wyes when the job is done and enter the locations on the record plats. Usually the foreman on the job is a graduate laborer, which is very much to the man's credit but rarely endows him with the type of ability required to make careful and accurate measurements.

Practically all small cities have spent much more money relocating unrecorded or inaccurately recorded sewer lines and wyes than the foremen on the jobs are aware of or are willing to admit.

All of the foregoing construction details and experiences have been discussed simply to emphasize that a well designed and well constructed sewer line is the easiest solution to any maintenance problem. Since the main-

tenance man is usually the man who constructs many minor extensions, and occasionally even larger ones, he should be well versed in the latest and best construction methods and materials.

Adequate Plumbing Ordinance Important

Next to good construction, the most important item of preventive maintenance is a good plumbing ordinance, well enforced. All the plumbing system, and particularly the house service connection, must be considered a definite part of the sewage collection system. A well written plumbing ordinance will assume this to be true. It will provide for root-proof construction, well trapped and vented fixtures, adequate cleanouts, and, most important of all, will prohibit the discharge of objectional materials to the sewer system.

The types of materials to be prohibited from entering the sewer will depend not only on the type of pipe and the slope of the sewer but also on the treatment plant, its capacity, and the process method employed. But no ordinance is any better than its enforcement. Therefore, the plumbing inspector and the sewer maintenance man should be on the most friendly terms. Objectionable materials found in the sewer during cleaning operations should be reported immediately to the plumbing inspector. The inspector in turn should locate and eliminate the source of such material. If the inspector fails to do this, then the sewer maintenance man is going to have to do it himself.

When any town adopts a revision of its plumbing ordinance the sewer superintendent should insist on his right to review those portions which have to do with or which may affect the sewer system or sewage treatment plant. One of the most important of these concerns house connections. Most cities rightfully and logically prohibit anyone other than city employees from installing these services between the city sewer and the property line. It has been the experience in Turlock that the most vulnerable spot in the whole sewer system, as far as root trouble is concerned, is at the connection of the house service with the main sewer. Almost any good workman can make a joint where there is a wye already in place but cutting through the pipe wall and placing a saddle or installing a new wye is a job for an expert and should be done by the man who best knows how. This man is not the plumber but the city employee, trained by his boss to do the job right. Even then the job should be checked by the inspector as a matter of policy, to insure careful work at all times. In addition, poured joints rather than cement mortar joints should be required by ordinance so that the joint will be as root proof as possible. It is usually much more difficult to remove roots from house services than from sewer mains.

Few city ordinances will permit the connection of rain water leaders to sanitary services except in those places where the sewers are combination sanitary and storm. Yet many of these same cities which prohibit such connections will construct storm water inlets from the streets to the sanitary sewers. This, of course, is always condoned as a temporary expedient but it behooves the sewer superintendent to be vigilant and to watch the street superintendent. Also he should remove existing storm water inlets as fast as it is practical to do so.

Conclusions

If all the precautions indicated by good design and good construction methods are followed and a good plumbing ordinance is enforced, nothing more than routine flushing and cleaning of sewers should be necessary. That, however, would be perfection and no city, regardless of size or number of employees, has ever constructed the

perfect sewer system. Accordingly, roots, sand accumulated sludge, odors, sticks, and stones will always be a problem and constant vigilance and much hard work too often will be the lot of a good sewer maintenance man.

DISCUSSION BY A. SEGEL *

The problems involved in the maintenance of sewers in the smaller cities of California are much the same fundamentally, but with some variations due to location, type of industries, and the design of the system itself. Mr. Davis, and others, have spoken of some phases of maintenance and operation, some of which are to be encountered in nearly every community.

The city of Fresno has its share of the usual problems. The sewers in the downtown area, where there are no trees, require cleaning about four times a year. This is due to the sand and oil from service station wash racks and grease racks, together with grease from restaurants and hotels. In one case recently, approximately 150 lbs. of caked grease was removed from one 400-ft. block of sewers. All of the house sewers of these business places are equipped with sand and grease traps, as required by ordinance.

Someone will immediately mention that this difficulty can be remedied by rigid enforcement of the intent of the ordinance, which is true. Enforcement, however, is difficult. There are several ways whereby a trap can be kept in continuous operation without anyone going near it with a shovel and bucket.

In the industrial area sewers are partially clogged by the combination of fine sand with the pulp and seed from fruit packing concerns and wineries, which forms a hard cake or layer in the pipe. The washing of the fine sand from raisins is now under much more rigid inspection by state food inspectors than was the case about two years ago. Consideration is now being given to an ordinance governing the pre-treatment of industrial wastes before discharge to the city sewers.

The tree-root problem in the residential area is an ever-present one. Some of the sewers are in right of ways with trees almost directly over the lines. Cement joint material is being used; the development of the new tar-base jointing compound now on the market is being watched with interest.

Another item of maintenance has resulted from the millions of cockroaches which appeared in the Fresno sewer system. Having observed the mass migration of bugs and insects in the Middle West, there should be real concern as to the effects on the public should these bugs suddenly decide to go elsewhere, en masse. There is also the health angle involved in the possibility of these roaches entering dwellings by means of vent pipes, especially where there are no traps on the house lateral. At Fresno these roaches have been practically eliminated, for the present, by spraying the manholes with "Roach Doom," a product especially designed for this purpose. Two applications were required, separated by an interval of about ten days.

It is not anticipated that the installation of sewers in curved and winding streets will offer any particular difficulty, even though the sewers are laid parallel with the center lines of the streets. These curves, as a rule, are not sharp so the sewer cleaning equipment should work equally well on these lines. There are several advantages gained by laying the sewers on a curve which more than offset the disadvantages of not being able to lamp from one manhole to the next for inspection purposes. These advantages are chiefly in the reduced number of manholes and also in the fact that the sewer lines are placed parallel with water and gas mains instead of crossing them at acute angles, causing difficulties in trenching.

Sewer cleaning equipment used in Fresno is somewhat different from that

* City Engineer, Fresno, Calif.

employed in most places. A collapsible canvas umbrella or parachute mounted on steel ribs or stays is forced through the sewer under water pressure. The parachute carries a steel cable and forces the sand and other matter ahead to the next manhole. If further cleaning is necessary, a stiff, steel brush larger than the pipe diameter is attached to the rear end of the cable. This brush is followed by a swab attached about 5 ft. behind the brush. The swab consists of a perforated disk, made of heavy belting, which forms a cutting or scraping edge against the wall of the pipe. This completes the operation in normal cases.

Occasionally sewer cleaning crews are faced with unusual circumstances, and such was the case last year. In 1916 a cast-in-place 46-in. concrete storm sewer with a 48-in. sanitary sewer directly below was installed in a street. In making repairs to a manhole leading to the lower section of the large main it was discovered that an 8-in. gas main entered and crossed the storm sewer section a little above the center. This condition was unexpected and not according to best practice, but upon entering the 46-in. storm sewer to work on the removal of the gas line it was found that a 12-in. vitrified clay pipe sanitary sewer also crossed the storm sewer at about the center. Thus, for 30 years the cross-sectional area of the overloaded storm sewer had been impaired and restricted approximately 30 per cent.

Venturing an explanation it is possible that the contractor intended to cut the 12-in. sewer into the lower sanitary section of the main sewer after the main sewer was completed, but that the matter was forgotten. Fortunately, no stoppage has occurred at this point during the long interval of time.

OPEN DISCUSSION

MR. HARVEY W. HOUSE, *Research Engineer, Pacific Coast Clay Products Institute, Los Angeles, Calif.:* Some of you may recall that we discussed this question of roots a year ago at the Calif. section convention, and in view of the fact that Dr. Davis and Mr. Segel have mentioned the importance of this matter it seemed appropriate to mention to you that we have been continuing work on this problem of a hot-pour compound for sewer pipe joints. The results which were reported in the paper published last March seemed to have been confirmed during the past year in our test lines. These conclusions were that if the compound was used in accordance with the specifications, known as CPI 2, it keeps out the roots under most conditions.

The only thing I wish to mention here, however, is that we have found that there is a serious detriment to the tightness of the joints if the joint is poured when the pipe is moist or wet. In past years certain manufacturers of hot-pour compound have given the impression that because the compound was hot it could be relied upon to separate the water in the pipe and thus make a tight joint. That is not true. The matter of greatest importance in these hot-pour joints is the adhesion between the compound and the pipe, and we find that adhesions have seriously weakened if the pipe is even moist. We regret that that is so because it imposes a rather serious difficulty in the use of hot-pour compound.

Various efforts are being made, however, to overcome that. We are now engaged in a program of research on various priming agents, because we have found that if the pipe is primed when dry, the joint can subsequently be poured when the pipe is moist and still get a tight joint. We are not ready to come out with a practical solution of that because we want to make a longer test.

In conclusion, I would simply like to say that while the Institute doesn't feel it has all the answers, we have made a good deal of progress, and if

any of you are interested in this problem and wish at any time to get the latest information as far as our research has developed it, you may communicate with either the manufacturers in your local territory, or directly with me, at my laboratory in Los Angeles. In that way I can give you the benefit of our knowledge as we have developed it up to the latest moment.

I say this because the subject is developing so rapidly that at any given week we are likely to know more than we did the week before.

INTERESTING EXTRACTS FROM OPERATION REPORTS

CONDUCTED BY LEROY W. VAN KLEECK

You never learn anything by saying
over and over the same thing.
—*Erich Maria Remarque*

Attention operators! It will be appreciated if copies of all annual reports of both large and small plants are sent to the Federation office for abstracting in this section of the Journal. Carbon copies of typewritten reports will be promptly returned on request. Please direct annual reports to: Federation of Sewage Works Associations, Room 325, Illinois Bldg., Champaign, Ill.

Fifteenth Annual Report on the Sewage Treatment Plant of the Aurora Sanitary District, Aurora, Illinois for the Year 1945 *

BY WALTER SPERRY, *Superintendent*

Operation of Generator Engines Saves Money

Had we purchased power, the total operating cost would have been $34,152 in place of the $29,494 reported herein. This was a reduction in plant costs due to plant-produced power of 15.6 per cent.

The District Loses a Good Man

One of the peculiar incidents was the resignation of Mr. Fred Schur, a very excellent man, who resigned with regret due to a peculiar physical condition which apparently could not be controlled even under a doctor's supervision. His nervous system was such that in the presence of slight local odors around the plant he continuously vomited. This was an old complaint. Working around the barn in the morning and at butchering time on the farm caused similar reactions. Apparently little could be done about it in the way of medical aid. We lost a good man. (*Abstracter's note:* This abstracter knows of several cases at the larger plants in Connecticut where new men reporting were unable to stick-it-out, as it were, for more than a few days. All of which seems strange indeed to those of us who can eat a sandwich with one (clean) hand and rake the bar screen with the other.)

Garden Harrow Removes Weeds

During a visit with Superintendent Mott of the Iowa City, Iowa plant an interesting stunt to control weeds in sludge beds was picked up in the use of a wheeled garden hoe with long cutter blades. If the beds are gone over with this tool when the weeds are small, the weeds are quickly and ef-

* For last previous extract see THIS JOURNAL, **18**, 4, 742 (July, 1946).

fectively eliminated. We found the scheme worked well at Aurora. (*Abstracter's note:* Wheel harrows adjusted to cut under the surface of the sand about ½ inch have also proven very effective and rapid weed removers at several Connecticut sand filter plants. They also break up the hard crust of sewage solids and delay the need of cleaning the beds. A home-made harrow consisting of a single suspended metal bar between two wheels makes a very effective device.)

Gas Engine Operation

The two 75-hp. pump engines went into their ninth year of operation in 1945. The two 50-hp. gas engine generator units went into their fifth year of operation in 1945. It has been the Aurora practice to completely overhaul all four engines annually in the spring of the year by regrinding valves, thoroughly cleaning oil ports, and checking for defective parts, including spring replacements as needed. Ordinarily rings are replaced every other year.

Grit Removal from Digester Proves Worth While

One of the interesting developments in digester problems occurred in December, 1945. Two-stage digestion had been in operation ten years. For this ten-year period the first-stage digester had never been disturbed or the digester discharged to the beds. In December there occurred a decided drop-off of gas production indicating poor digestion. An examination of the digester indicated that there was a very considerable accumulation of completely inert material, part of which was found piled up on the square corners at the bottom and part of it was undoubtedly in the heavy layers in the scum material at the top, since this digester had no scum arm operating and is not provided with any circulating device either internally or externally. Material sampled from the bottom ran as high as 15 to 20 per cent solids almost devoid of volatile matter. This indicated that during the ten years of operation a very considerable volume of the digester was filled up and rendered completely inactive. It sharply pointed to the need of completely discharging and cleaning the digester and starting over.

Anticipating the 1946 Annual, it might be briefly stated here that this clean-out was accomplished in 1946 and that the operating results following cleaning and restarting were vastly different. The per cent of gas, for instance, produced in first stage in December, 1945 was but 43 per cent whereas in December of the preceding

TABLE I.—Summary of 1945 Operating Data, Aurora (Illinois) Sanitary District

Item	Average
Population served	51,000
Administration and operation cost ($)	36,435.89
Cost per m.g.	14.86
Cost per capita per year	0.71
Cost per capita per month	0.06
Sewage flow (m.g.d.)	6.72
Screenings (cu. ft. per m.g.)	1.1
Grit (cu. ft. per m.g.)	4.4
Gas production (cu. ft. per day)	46,560
Primary sludge:	
Total solids (%)	4.7
Volatile matter (%)	74.1
Secondary sludge:	
Total solids (%)	4.4
Volatile matter (%)	64.9
Transfer sludge:	
Total solids (%)	2.3
Volatile matter (%)	56.8
Digested sludge to beds and river:	
Total solids (%)	4.8
Volatile matter (%)	56.7
Supernatant:	
Total solids (%)	0.5
Suspended solids:	
Raw (p.p.m.)	196
Settled sewage (p.p.m.)	75
Filtered sewage (p.p.m.)	41
Secondary effluent (p.p.m.)	21
Per cent removal, total	89.3
B.O.D.:	
Raw (p.p.m.)	120
Settled sewage (p.p.m.)	71
Filtered sewage (p.p.m.)	24
Secondary effluent (p.p.m.)	14
Per cent removal, total	88.3
Filters and secondary tanks operated, per cent of time	92.1

year 78 per cent was produced. The per cent of gas produced in first stage in the latter part of August and the first part of September, 1946 jumped to 85 to 90 per cent, clearly justifying the necessity for cleaning and very likely indicating that the cleaning out of the first-stage digester could reasonably be justified at five-year intervals.

Eighth Annual Report of the Sewage Treatment Works for Battle Creek, Michigan for the Year 1944 *

By N. G. Damoose, *Director of Public Service*

Type of Plant

This is a primary treatment plant with separate sludge digestion.

Use of Liquid Sludge as Fertilizer

The 1939 report introduced the experimental work with sludge as a liquid fertilizer. There seems to be little doubt of the efficacy of this material in the liquid form and its extensive promotion is retarded only by the lack of tank and truck facilities, and manpower. The 3-in. pump now used has solved the not too serious clogging difficulties of 1939–40, when a 2-in. pump was used.

As indicated in previous reports, it is not economically practical to apply the sludge with tank equipment of less than 1,000-gal. capacity and this, together with a truck to carry a full load, is not at present procurable.

It is anticipated that with the new primary digester in operation the question of insufficiently digested sludge for liquid fertilizer will be removed.

Liquid fertilizer is still distributed gratis to anyone who wishes to carry it away. The nine acre lawn area about the plant was well maintained during the year and treatment with liquid fertilizer has produced an incredibly thick mat of grass throughout the entire area.

Regulatory Policy Suggested for Harmful Wastes

It is respectfully suggested that the city establish a regulatory policy with regard to certain wastes and materials entering the collection system. Reference is made only to those wastes which are indisputably foreign to sewage such as rubbish, wire, linoleum, tin cans and pails, grease, oil, strong and

TABLE II.—Summary of 1944 Operating Data, Battle Creek, Mich.

Item	Average
Population served	57,343
Equivalent population served:	
On basis of B.O.D.	59,800
On basis of inf. susp. solids	75,700
On basis of inf. vol. susp. solids	78,200
On basis of vol. solids, raw sludge	92,500
On basis of gas production	80,800
Average equiv. population	77,400
Total operating costs ($)	28,992.79
Per day	79.22
Per m.g. sewage	11.81
Per capita per year	0.51
Total maintenance costs ($)	2,180.43
Per day	5.96
Per m.g. sewage	0.89
Per capita per year	0.04
Sewage flow (m.g.d.)	6.69
Grit (cu. ft. per month)	43.2
Grit, per cent organic matter	64.5
B.O.D.:	
Influent (p.p.m.)	171
Effluent (p.p.m.)	103
Per cent reduction	39.8
Suspended solids:	
Influent (p.p.m.)	284
Effluent (p.p.m.)	84
Per cent reduction	70.4
Settleable solids (ml. per liter):	
Influent	7.3
Effluent	0.2
Per cent removal	97.1
Digested sludge:	
Moisture (%)	97.3
Volatile matter (%)	71.5
Supernatant (per cent moisture)	98.5
Gas production:	
Cu. ft. per capita per day	1.41
Cu. ft. per month	80,676

* For the last and only previous extract see This Journal, **13**, 5, 973 (Sept., 1941).

heavy acids, alkalies and other similar materials. The plant is ready and prepared to serve its owners and users in the treatment of all domestic and industrial wastes of a character which will not foul its biological process, damage its equipment, or accumulate at points in the system where they cannot be reached, controlled, or disposed of in some reasonable manner.

The enforcement of any legal authority adopted for the purpose of regulating the disposal of such materials should not exceed the right to counsel with and advise business and industrial enterprises from which such wastes are discharged. It should not extend to the usual conception of police power. Business and industry cannot be curtailed because they produce wastes any more than life can be curtailed because it produces sewage. Industry and business can find means of proper disposition of their waste, thus avoiding difficulties in, and interference with, the normal operation of the plant. Special care must be exercised in enforcing such regulatory measures in order that the public goodwill may be maintained at all costs, and the problem solved to the convenience of the taxpayer or citizen, to the satisfaction of the city, and to the protection of the plant.

Effectiveness of Plant Operation

Study and analysis of the foregoing discussion and the tabulations of this report will no doubt indicate the continued effectiveness of plant operation. High removals of suspended solid matter, increases in gas production, and a sizable cash balance are but a few of the evidences of the technical and administrative efficiency of the plant's operation.

Sustained improvement of the Kalamazoo River is indicated by the odor nuisance elimination, which is now practically complete. This is tangible, sensory evidence, readily detectable and appreciated by the public. Several voluntary expressions of appreciation for the plant and its operation have been received.

Thirteenth Report of the Minneapolis-Saint Paul Sanitary District for the Year 1945 *

By George J. Schroepfer and Warren H. Sleeger, *Superintendent and Acting Superintendent*

Change in Superintendents

Kerwin L. Mick, who has been in the employ of the Metropolitan Drainage Commission since July 13, 1931, and made Chief Chemist by the Sanitary District, November 1, 1933, was appointed Chief Engineer and Superintendent by the Board at its meeting of July 9, 1945, effective upon his return from military service. As the year drew to a close, word was received that Mr. Mick was expected to return to the District and assume his new duties in the very near future.

Following Mr. Schroepfer's resignation to accept a position as Professor of Sanitary Engineering at the University of Minnesota, Mr. Warren H. Sleeger was appointed by the Board, at its August 13th meeting, as Acting Chief Engineer and Superintendent, effective September 16, 1945, for the interim period between then and the time Mr. Mick returned.

Inoculations

Continuing its policy of safeguarding the health of its employees, the

* Report received 1947 Hatfield Award. For the last extract see This Journal, **19**, 3, 498 (May, 1947).

Board of Trustees authorized reinoculation of all employees against typhoid and paratyphoid fever. This was done at the District's expense.

Washing Headers of Vacuum Filters Placed Under Discharge Aprons

During this year the washing headers on the vacuum filters were all rebuilt to permit either continuous washing or intermittent washing without requiring the filter to be removed from operation during the washing. This new method of washing the filters has reduced sludge filtration costs. Determination of the relative economics between continuous and intermittent washing awaits further data. Using either method, the new location of the washing headers permits continuous discharge of filter cake with no interruptions for washing, increases the filter area available, and produces a more even tonnage to the incinerators.

TABLE III.—Summary of 1945 Operating Data, Minneapolis-Saint Paul Sanitary District

Item	Average
Estimated tributary population	840,000
Sewage flow (m.g.d.)	118.6
Screenings, total cu. ft.	38,918
Grit, total cu. ft.	186,750
Filter cake produced (tons)	97,703
Screenings (cu. ft. per m.g.)	1.0
Grit (cu. ft. per m.g.)	4.6
D.O. settled effluent (p.p.m.)	4.1
Settling tank detention (hr.)	1.1
B.O.D.:	
Raw (p.p.m.)	190
Settled (p.p.m.)	120
Per cent removal	37
Suspended solids:	
Raw (p.p.m.)	300
Settled (p.p.m.)	100
Per cent removal over-all (screenings and grit included)	70
Settleable solids:	
Raw (ml. per liter)	8.4
Settled (ml. per liter)	1.8
Per cent removal	76.9
pH:	
Raw sludge	6.0
Thickened sludge	5.9
Filtrate	9.6
Total solids (%):	
Raw sludge	8.2
Thickened sludge	9.0
Filter cake	31.9
Volatile solids (%):	
Raw sludge	68.2
Thickened sludge	67.1
Filter cake	63.7
Suspended solids in filtrate (p.p.m.)	125
Raw sludge:	
Gal. per month	317,000
Dry tons per month	111.5
Conditioning chemicals:	
Lime, per cent CaO dry basis	2.84
Ferric chloride, per cent dry basis	0.92
Filter rate, lb. wet cake per sq. ft. per hr.	10.2
Lbs. wet cake per sq. ft. filter area used	0.85
Filter cake as fertilizer, total tons for year	4,545.0
Filter cake incinerated, dry tons daily	78.0

Different Mesh Sizes for Filter Screens Tried

Experiments were conducted on different mesh sizes for the Oliver filter screens, which serve as a backing for the filter cloths, with the purpose of determining whether a larger percentage of opening would have any marked effect on the filter yields. Results showed a slightly greater filter yield with the coarser screens, amounting to 4.8 per cent for a 2½-mesh screen and 4.4 per cent for a 3-mesh screen, as compared with the original type 5-mesh screen.

Comparative Study Made on Solvents For Grease Determination

A comparative study of using ethyl ether and petroleum ether (B.P. 40°–60° C.) as solvents in the determination of grease in sewage sludge was made. Acidification and final extraction yielded the following average results on six composite samples:

	Grease Percentage	
	Ethyl Ether Solvent	Petroleum Ether Solvent
Sludge	21.1	17.1
Filter cake	19.6	14.7

It is felt that while petroleum ether gives lower values, they are more representative of the actual grease content of the sludge, since they probably do not include some of the soaps.

Studies Made on Effective pH Range for Sludge Filtration

Studies were continued toward determining an effective pH range for chemical conditioning of the sludge with the purpose of eliminating the troublesome carbonate depositions in the sludge lines and vacuum filters. Although laboratory studies determined that the stability pH of the conditioned sludge lay in the range between 8.2 and 8.5, a more serious condition than the carbonate deposition was encountered when this pH range was used for a lengthy period of plant filtration operations.

Filtering at a pH of 8.5 or less caused a slimy bacterial mold formation, very gelatinous in appearance, to form on the filter screens, division strips, and pipe lines. This mold condition was much more difficult to remove than the calcium carbonate depositions formed at higher pH operations. Further tests under actual plant conditions resulted in a decision to attempt to control the pH of the conditioned sludge in the range of 9.0 to 10.0. This resulted in only a minimum amount of carbonate deposition. However, several periods of difficult filtering were encountered and at such times it was necessary to increase the pH above 10.0 in order to maintain the necessary tonnage output.

1946 Annual Report on the Sewage Treatment Plant for the City of Dallas, Texas *

By L. C. Billings, *Superintendent and Chief Chemist*

Description of Plant

This plant is a trickling filter plant of 32 m.g.d. capacity. The treatment units include primary treatment by both Imhoff tanks and primary settling tanks, 16 rock filters of 8.93 acres area, final secondary sedimentation tanks, 35 m.g.d. pumping capacity for recirculation of secondary tank effluent, and two-stage separate sludge digestion.

Systematic Flooding of Filters Considered Best Fly Control Method

Results lead us to conclude that the initiation of a systematic flooding program early in the spring will be as effective for *psychoda* fly control in the trickling filters as any control measures known at the present time. Chemical treatments are hard to control and very expensive for effective application. (*Abstracter's note:* See further discussion on use of DDT below.)

Grounds Maintenance

A flock of sheep has been kept on the grounds for several years for the purpose of reducing grass and certain weed growths in the unoccupied areas. The sheep serve for a part of the job. However, the good they do is offset by the damage they do to roses, young pines, and other shrubbery. Financially, sheep maintenance has been in the red. For the three calendar years 1944, 1945 and 1946 total income from sheep has been $408.81. Total expense has been $454.25 with a 50 per cent reduction in flock over this period.

Drinking Water Supply for Employees Found to be Contaminated by Handling

Among needed improvements is an extension of the city water supply to the plant. Present well cistern is not a satisfactory drinking supply, and generally unsuited for laboratory use. The present drinking water supply is collected in 5-gal. bottles and carried

* For a previous extract see This Journal, 19, 4, 667 (July, 1947).

to a cooler. Handling these bottles with unclean hands produces a health hazard of major importance to employees. Laboratory check-ups indicate a contaminated drinking supply despite many attempts to instruct handlers. (*Abstracter's note:* This is a finding which should be of considerable interest to all users of bottled drinking water supplies. The source may be safe but the handling can contaminate the water.)

Filter Fly Control Studies

Sodium Chloride. Laboratory tests were made in January, using sodium chloride as a contact insecticide for the filter fly larvae. Tests were made by placing 100 larvae in each of 0.1, 0.5 and 1 per cent sodium chloride solution. After two hours all larvae were still active. With a 5 per cent solution all larvae were destroyed within 50 minutes. No tests were made of the effect of sodium chloride on filter rock growth. The cost of flooding the filters with a 5 per cent salt solution would be prohibitive. However, it could possibly be used at a smaller plant.

Flooding. In June, A-2 filter was flooded with untreated sewage and kept in that condition for 48 hours. About three cubic yards of larvae, destroyed by suffication, were removed before draining.

DDT. In June the effect of DDT on filter larvae was studied. A-1 filter was filled with sewage containing 1/8 p.p.m. of DDT, then immediately drained. No reduction in number of larvae was noted. A-2 filter was filled with sewage containing 1/4 p.p.m. of DDT. After being completely flooded for two hours, it was drained. Only a few larvae were destroyed.

In August and September the effect of DDT as a contact insecticide for the adult filter fly was studied. Based on the theory that the fly could be controlled providing a sufficient number come in contact with a DDT coated

TABLE IV.—Summary of 1946 Operating Data at Dallas, Tex.

Item	Average
Estimated population served	484,000
Miles of sanitary sewers	750
Sewage flow at plant (m.g.d.)*	25.3
Cost of operation ($):	
Total	44,463.31
Cost per m.g.	4.80
Screenings (cu. ft. daily)	26.3
Grit (cu. ft. daily)	89.0
Screenings (cu. ft. per m.g.)	0.86
Grit (cu. ft. per m.g.)	5.8
Settleable solids (ml. per liter):	
Raw	8.9
Primary tank effluent	0.2
Imhoff tank effluent	0.4
Filter effluent	0.8
Final tank effluent	0.2
B.O.D. (p.p.m.):	
Raw	324
Primary tank effluent	199
Imhoff tank effluent	209
Filter effluent	46
Final tank effluent	31
Dissolved oxygen (p.p.m.):	
Filter effluent	4.2
Final tank effluent	4.7
Suspended solids (p.p.m.):	
Raw	348
Primary settling	91
Filter effluent	71
Secondary settling	35
Sludge data:	
pH:	
Primary tank sludge	6.2
Transfer sludge	6.8
Secondary digester sludge	7.1
Supernatant	7.1
Imhoff tank sludge	6.1
Secondary settling tank sludge	6.6
Per cent dry solids:	
Primary settling tank sludge	4.8
Transfer sludge	3.1
Secondary digester sludge	6.0
Supernatant	1.5
Imhoff tank sludge	5.2
Secondary settling tank	3.8
Per cent dry volatile solids:	
Primary settling tank sludge	78.8
Transfer sludge	59.1
Secondary digester sludge	54.5
Supernatant	54.3
Imhoff tank sludge	72.2
Secondary settling tank sludge	66.7
Trickling filter data:	
Sewage applied (m.g.a.d.)	4.54
Loading (5-day B.O.D.):	
Lbs. per acre per day	7,584
Lbs. per cu. yd. stone	0.62
Lbs. per acre-foot	1,017

* Some flow by-passed.

surface, all filters were sprayed with a 10 per cent DDT kerosene solution at the following surfaces: the concrete center portion, the 6- to 12-in. strip of dry rock at the outer edge of the filter, and the inside portion of the concrete wall around the filters. DDT was applied at the rate of 0.02 oz. of powder per sq. ft. of sprayed surface. Results were disappointing.

Bolding has observed that the filter fly prefers the shade. For this reason the elimination of weeds and tall grass in the filter field would be desirable.

In summary, results with DDT were disappointing. Best results were obtained by flooding the filters for at least 24 hours.

(*Abstracter's note:* Adult fly control at other plants has also proven to be disappointing in many cases. It must be remembered that large numbers of flies are in the area around the filters, such as in tall weeds, and also inside the filters themselves. The results at this plant with larvae control might have been more successful if higher strengths of DDT had been used. It will be noted that the doses tried were relatively light.)

TIPS AND QUIPS

Many Enjoy Conducted Tour to 20th Annual Meeting

For many, an outstanding feature of the recent combined FSWA–AWWA meeting at San Francisco was the delightful tour to and from the convention, which was arranged by the Joint Transportation Committee. One hundred seventy-seven Federation and AWWA members and guests made the trip to San Francisco aboard the special train provided by the committee. Particularly enjoyed were the sightseeing tours en route at Rocky Mountain National Park; Salt Lake City; Hoover Dam; Las Vegas, Nev.; and the Los Angeles area.

In the Los Angeles area local FSWA and AWWA members did an exceptional job of entertaining the special tour members. Transportation and guide service were available to many places of engineering interest.

In addition to the special train arrangements the Transportation Committee took care of direct transportation routings between New York and San Francisco for 22 members. Committee members at Chicago also arranged for a special car to San Francisco and booked space for 18 individuals.

The long return trip from San Francisco, which featured a boat trip to Victoria, B. C. and a 3-day stopover in Glacier National Park, was enjoyed by 127 persons, the majority of whom had been together on the westward trip. The committee also handled reservations for 54 individuals who returned East by direct train.

Unless one has had first hand experience, it is impossible to realize the tremendous amount of work required of the Transportation Committee. E. A. Sigworth, chairman of the committee, reports that over 600 personal letters and 600 form letters concerning transportation arrangements were mailed from his office alone. All members of the committee cooperated completely; many spent considerable time and corresponded extensively with Federation and Association members. Tom Amiss, of Shreveport, La., in particular, worked extremely hard and diligently to develop a special train for members from the Southern States. Although widely publicized there were not sufficient requests for space to make the Dixie Special a reality.

One outstanding service of the committee was its timely notification to tour members of the June 1st rail-

road fare increase and its advance purchase of tickets for those having tour reservations. This action by the committee resulted in an estimated saving of approximately $4,000 to those making the tour.

The Federation's sincere thanks and appreciation are due the Joint Transportation Committee members for their successful handling of a difficult job.

Kessener Visits

Federation headquarters recently was favored with a visit by Dr. H. J. N. Kessener of The Hague, Holland, who was on a tour of the U. S. for the Netherlands government in his capacity as technical advisor on water pollution. Dr. Kessener has retired from his former position as director of the Government Institute of Sewage Purification. He held the earliest patent covering the utilization of sewage gas for power (1914), and is the inventor of the Kessener Brush Aerator, which has found application in a number of European activated sludge plants.

Dr. Kessener is a strong believer in the activated sludge process of secondary treatment and holds that, per unit of volume, it is a less expensive method than is biological filtration. Citing several plants in Europe where concentrated industrial sewages are treated successfully by activated sludge, he discounts the alleged disadvantages of the process with respect to ability to handle such wastes, requirement of highly skilled supervision, and economy in small installations.

Of further interest to us was Dr. Kessener's description of mechanical devices used commonly in Holland, such as water wheels powered by the sewage flow for activated sludge return and large, slow-moving stirring plates or paddles—operating from a horizontal shaft—in digesters (see THIS JOURNAL, **18**, 1, 22; January, 1946).

In the course of his inspection trip of sewage works in the U. S., Dr. Kessener was especially impressed with their cleanliness and the attention given to beautification of buildings and grounds.

The opportunity to visit with Dr. Kessener was most enjoyable. One of the pioneers in modern sewage treatment practice, he is full of new ideas and has retained his enthusiasm for his work in spite of the harrowing experiences to which he and his family were subjected during the war. We look forward to the faint possibility that there may some day be a chance to return his visit.

Home Garbage Grinders

Home garbage grinders apparently not only are here to stay but may soon arrive in most communities in appreciable numbers. The General Electric Company has announced the end of allocations on its Disposall unit. At the end of 1946, production of Disposalls reached a rate four times the maximum pre-war rate. Current quotas point to a 1947 production several times the 1946 figure.

A new home garbage grinder recently made its appearance on the West Coast, the Waste King, produced by the Arvin Manufacturing Company of Los Angeles.

All sewage works operators who have wishfully viewed the home garbage grinder as a passing fad would do better to take a serious look at this fast-growing infant of the appliance field. The home garbage grinder already is in the future of every sewage works operator!

Quarter-Century Operators' Club

Although there were no functions specifically scheduled for its members, the Quarter-Century Operators' Club was well represented at the 20th Annual Meeting at San Francisco. Frank Woodbury Jones, head man of the venerable group, announced a new club

member whose election had not been previously reported. New member Earl Devendorf, Assistant Director, Division of Sanitation, New York Department of Public Health, is an old-timer in the sewage works field, having paved the way for John Lewis, A. H. Goodman, and Morris Cohn at the Schenectady, New York, plant between 1915 and 1918.

The roster of the Club now includes the names of 30 veteran valve turners.

The Quarter-Century Club Committee, appointed last year by President Friel, has formulated plans for administering the affairs of the Club so that the privileges of present members will be protected, new applicants fairly considered, and the distinction and honor of membership maintained and preserved.

Insecticide Fog Generator

At some time or other every sewage works operator could use power spray equipment to advantage. Equipment making possible positive control of adult filter flies which have lodged on plant structures and in the grass and shrubbery would be welcomed by many. Occasionally destruction of fly larvae on sludge bed and lagoon surfaces is desirable. Other uses for power spray equipment at sewage plants readily come to mind.

The relatively new Todd Fog Applicator appears to provide the equipment answer for many insect control problems and has found wide application by municipalities for use at parks, beaches, playgrounds, stables, and dumps. Adapted from equipment developed for the Navy, the machine can distribute any standard insecticide, weed-killer, or fungicide, converting it into a super-fine fog of controllable density.

As a fog, the insecticide can be distributed over an area more thoroughly than by other methods since the fog moves across the ground enveloping and penetrating everything encountered.

The fogging method is claimed to be considerably more economical because it spreads the lethal agents much thinner, reportedly requiring only about 1/20th of the total materials required by other methods to do a given job. The fogging method is also claimed to be much faster, with the fog traveling for distances up to 600 ft., with high kill. The machine can be operated by one man who can also drive the truck or jeep on which the fog applicator is mounted.

Belt-driven for smoother operation and powered by a standard gasoline engine, the fog applicator has a particle size range of ½ micron (1/2,000th of an inch) to 135 microns, which is virtually spray size. One recent job accomplished with dispatch by a Todd Fog Applicator was the fogging with DDT of the entire Texas City, Texas area immediately after the disastrous blasts which damaged the town and disrupted normal sanitary services.

If the cost is not excessive, the fog applicator may have enough general use that some municipalities will add it to their equipment pool. Where this occurs it may be worth while for the sewage works operator to borrow or rent the fog applicator and to determine its suitability for occasional insect and weed control use at sewage treatment works.

CSSWA Again Wins Convention Attendance Award

For the sixth consecutive time the annual Convention Attendance Award was won by those traveling midwesterners of the Central States Sewage Works Association. Whether compelled by loyalty to the Federation annual meeting, a curiosity to see for themselves how golden California really is, or just a desire to get away from midwestern summer weather, the CSSWA members rolled up an impres-

sive 41,000 man-miles in coming to San Francisco. At first it appeared that the California delegation might break the long CSSWA reign, but the 146 Californians registered could total up only slightly more than 30,000 man-miles, to take second place. The Pennsylvania Association captured the show position, with New York taking fourth place.

This latest capture of the Attendance Award retires the second consecutive trophy to the permanent possession of the CSSWA.

Deciding that the Convention Attendance Award had outlived its usefulness, the Board of Control acted at San Francisco to abandon the contest. C. C. Larson, CSSWA Director, in commenting on this action advised that his constituency would not feel too badly about the suspension of the competition. The responsibility for preservation and transportation of the two trophies actually has been more of a penalty than a reward.

Flash From 'Frisco

The unscheduled highlight of the Joint Presidents' Reception and Dance at the recent Annual Meeting was, without a doubt, the impromptu hula dancing lesson received by a group of water and sewage works notables. During the Hawaiian entertainment the mistress-of-ceremonies, famed Hilo Hattie, beguiled a somewhat wary group of celebrities to line up for a hula lesson.

Placing them at once at ease, Hattie started the lesson. With doubtful eyes riveted on undulating Hattie and lured on by the music of The Islands, the pupils tried mightily. The snapping of long forgotten muscles accented the rhythm of the guitars.

Complete honesty compels reporting, however, that despite earnest effort Hilo Hattie's "curvilinear" contortions coaxed only "wrecktilinear" reactions from the weak but willing pupils.

There were no reported casualties!

Editorials

THE STANDARD METHODS COMMITTEE

The Federation's Committee on Standard Methods of Sewage and Industrial Wastes Analysis, under the leadership of Chairman W. D. Hatfield, is engaging in an ambitious program of activity that is deserving of special notice. Though the committee has worked quietly in the past, it has nevertheless done an extraordinary job in compiling the sections on sewage methods contained in the eighth and ninth editions of *Standard Methods for the Examination of Water and Sewage*. The new responsibilities assumed recently by the committee establish its program as one of the Federation's foremost current activities.

Worthy of first mention is the fact that the Federation will be a full-share participating publisher with the American Public Health Association and the American Water Works Association in the production of the next (tenth) edition of *Standard Methods*. The ready acceptance of the Federation as a joint sponsor and publisher is undoubtedly a result of the excellence of the contributions made by Dr. Hatfield's committee to the current and preceding editions of this vitally important manual.

Then there is the research project that was initiated by the committee in October, 1947, under a $33,830 grant from the National Institute of Health. Objectives of the project are to evaluate existing analytical methods as to their accuracy, analyze their shortcomings and, where possible, to develop new or improved technics.

The work will be conducted under the general direction of Chairman Hatfield in six established sanitary chemical laboratories, each of which is under the immediate supervision of a member of the committee. At this writing, work is progressing at the Massachusetts Institute of Technology under the direction of Dr. Clair N. Sawyer, and at the University of Wisconsin under Dr. M. Starr Nichols. Other laboratories being considered are those at the New York State Division of Laboratories and Research (F. W. Gilcreas), the Illinois State Water Survey (Dr. A. M. Buswell), Rutgers University (Dr. Willem Rudolfs), Mellon Institute of Industrial Research (Dr. R. D. Hoak) and Purdue University (Prof. Don E. Bloodgood).

Each laboratory will be assigned specific analytical methods for detailed study. One full-time technician or the equivalent in part-time workers will be employed in each laboratory.

High hopes are held for the productiveness of this research. Advancements in analytical procedures have heretofore depended upon voluntary studies, more or less coordinated, that could be undertaken as time permitted. As a result, some methods have been continued as "standard" procedures when they are known to be deficient; others have become obsolete soon after adoption as "standard." The comprehensive and coordinated work made possible by the NIH grant should advance by several years the normal progress made in analytical procedures.

Finally, the committee last year expanded its functions to include industrial waste analytical methods by assigning three of its members to serve as a special subcommittee. This is in line with the general policy of the Federation in regard to increased emphasis on industrial waste interests.

It is apparent that the Federation, through its Committee on Standard Methods of Sewage and Industrial Waste Analysis, is prepared to fulfill the responsibility that it has assumed in becoming a partner to APHA and AWWA in publishing the *Standard Methods* manual.

PLATING INDUSTRY TO STUDY WASTE DISPOSAL

Welcome news is the recent announcement by the American Electroplaters' Society that a new research project has been established to include studies on plating waste recovery and disposal. The work will be undertaken in the Department of Chemical Engineering at Yale University under the direction of Prof. Barnett F. Dodge, who will be assisted by D. C. Reams. The AES Project Directing Committee consists of Dr. C. Fred Gurnham as chairman, with Malcolm A. Orr and Manley L. Ross.

An extensive survey and critical review of the existing literature on metal plating and finishing wastes will initiate the project. This will be followed by laboratory and pilot plant investigations, and by cooperative work in industrial treatment plants. There is also a need for basic information on toxicity limits of various components of metal plating wastes, and studies in this direction might desirably be included under the project.

It is only through such intra-industry research as this that the final answers to difficult industrial wastes problems can be reached. The American Electroplaters' Society will serve its membership well by carrying out this program on a proper scale.

THE AMENDED BARKLEY–TAFT BILL

The amended version of the Barkley-Taft Bill (S. 418), passed by the Senate on July 17, 1947, deserves the active support of all who believe that federal pollution control authority should supplement and not be superimposed upon state authorities. By its clear provision that federal enforcement procedure is to be instituted only with the consent of the state or interstate pollution control agencies involved, S. 418 as amended represents the type of federal legislation that is held to be most useful by those who are experienced in the conduct of pollution abatement programs. Some conservationists, however, consider the bill to lack "teeth," and are marshalling forces to restore controversial clauses when the measure comes before the House upon the re-assembly of Congress next January.

Another amendment made in S. 418, which has been the source of some misunderstanding, is the reference to certain administrative functions that would be handled in the Federal Works Agency. As passed by the Senate, the bill assigns responsibility for the investigation of causes and sources of pollution, the recommendation of remedies and the justification of expenditures to the Public Health Service of the Federal Security Agency. The Federal Works Agency, however, is designated to perform the functions having to do with execution of the remedies, e.g., review and approval of plans, specifications, cost estimates, bond issues, etc., where federal loans for planning or construction are involved. This is merely a specific definition of the services which were intended to be assigned to agencies other than the Public Health Service under the general provision in the original bill which gave the Surgeon General authority to utilize "an appropriate agency of the United States" for the above purposes.

A further desirable change is the provision for federal financial assistance in the form of loans instead of grants-in-aid. Up to $100,000,000 per year would be appropriated for loans at 2 per cent interest to finance as much as one-third the cost of construction of sewage or industrial waste treatment works. An appropriation of $12,000,000 is authorized for loans without interest to finance preliminary engineering expenses. An additional $5,000,000 per year is made available to states for the conduct of special investigations and studies.

It is believed that the Barkley-Taft Bill in its present form is a sound and workable measure, and that its passage by the House of Representatives should be encouraged.

W. H. W.

Proceedings of Member Associations

CALIFORNIA SEWAGE WORKS ASSOCIATION

19th Annual Meeting

San Francisco, Calif., July 21–24, 1947

Acting as host to the 20th Annual Meeting of the Federation, the California Sewage Works Association held its 19th Annual Meeting concurrently with that of the Federation at San Francisco, July 21–24, 1947. One hundred forty-six members of the Association, exclusive of manufacturers' representatives, registered for the Federation meeting.

The only formal session held by the Association was the annual Business Luncheon, July 24, 1947, at the Whitcomb Hotel. President G. A. Parkes presided. Ninety members were in attendance.

Federation President Friel and Executive Secretary-Editor Wisely were guests of the Association and spoke briefly concerning the fine hospitality extended by the Association to Federation members attending the annual meeting. They also expressed appreciation for the outstanding way Association members had carried out the work of the various local arrangements committees.

President Parkes introduced Association members who had served on the local arrangements committees for the Federation meeting and they were given a rousing vote of appreciation and thanks. Secretary-Treasurer Arthur G. Pickett presented his report for 1947. Containing several specific recommendations concerning Association activities and policies for 1948, the report documented the healthy condition of the Association and its sound financial position. The reports were adopted and the recommendations referred to the Executive Board.

Fred Nelson, Chairman of the Membership Committee, reported on the activities of this committee for 1947 which resulted in the addition of an appreciable number of new members during the year. Active membership was reported as 330, with a special effort being planned by the committee to obtain the early reinstatement of 47 deliquents.

Following the report of the nominating committee, officers elected for 1947–48 were:

President—Harold L. May, Palo Alto.

Vice-President—Ray L. Derby, Los Angeles.

Second Vice-President—R. R. Ribal, Oakland.

Secretary-Treasurer—Lawrence H. Cook, Menlo Park.

Association Director—H. B. Foster, Jr., Berkeley.

ARTHUR G. PICKETT
Secretary-Treasurer

CENTRAL STATES SEWAGE WORKS ASSOCIATION

20th Annual Convention

Duluth, Minnesota, June 20–21, 1947

The 20th Annual Convention of the Central States Sewage Works Association was held June 20–21, 1947, in the Spalding Hotel at Duluth, Minn. A

total of 108 members and guests were registered.

President E. J. Beatty presided over the first session which was opened with an address of welcome by Mayor George W. Johnson of Duluth, Minn. Reports were presented by the Secretary-Treasurer and the Awards Committee.

"B.O.D. and Nitrification" by E. Hurwitz, G. R. Barnett, Harry Kramer and R. E. Beaudoin was the first technical paper presented. This was followed by "Biological Aspects of Stream Pollution" by A. F. Bartsch, senior biologist of the Committee on Water Pollution of the State of Wisconsin.

"Sewage Treatment at Madison, Wisconsin" was presented by Carleton H. Becker and M. D. Ridell of Greeley and Hansen Engineers.

"Studies on B.O.D." by C. C. Ruchhoft, O. R. Placak and M. D. Ellinger of the U. S. Public Health Service, Sanitary Engineering Division.

"Preaeration" by Donald Walker of Walker Process Equipment, Inc.

"Industrial Waste Treatment at South St. Paul" by William Cropsey and Keith Larson, superintendent and chemist, respectively, of South St. Paul disposal plant.

At the annual banquet Dr. J. E. Christianson, superintendent of the University of Minnesota School of Agriculture, gave an inspiring talk on the need for professional people to take more active interest in national and world affairs.

The George W. Radebaugh Award was presented to L. S. Kraus, chemist of the Greater Peoria Sanitary District of Peoria, Ill., for his paper "Use of Digester Sludge and Digester Overflow to Control Bulking Activated Sludge." This paper was presented at the June 13, 1946 meeting and appeared in the November, 1945 issue of THIS JOURNAL.

The second day of the meeting opened with an Operator's Breakfast which was a huge success. The one-half day which was allotted for this function seemed all too short for the enthusiasm evidenced.

The following officers were elected for the year 1947–48:

President: H. G. Rogers, Minneapolis, Minn.

First Vice-President: Carl B. Carpenter, Hammond, Ind.

Second Vice-President: L. S. Kraus, Peoria, Ill.

Third Vice-President: H. T. Rudgal, Kenosha, Wis.

Secretary-Treasurer: Paul W. Reed, Indianapolis, Ind.

H. G. Rogers announced that several cities had submitted bids for the CSSWA 1948 convention. The city of Milwaukee was selected.

PAUL W. REED
Secretary-Treasurer

MEMBER ASSOCIATION MEETINGS

Association	*Place*	*Time*
New York State Sewage Works Association	Hotel Pennsylvania, New York City, N. Y.	Jan. 23, 1948
New Jersey Sewage Works Association	Hotel Stacy Trent, Trenton, N. J.	March, 1948
Montana Sewage Works Association	City Auditorium, Livingston, Mont.	Apr. 8, 1948
Pacific Northwest Sewage Works Association	Hotel Boise, Boise, Idaho	May 12–15, 1948

Federation Affairs

GEORGE S. RUSSELL ASSUMES FSWA PRESIDENCY

George Silas Russell of St. Louis, Mo., became the eighth President of the Federation when he took over the gavel at the 1947 Annual Meeting of the Board of Control at Philadelphia on October 10, 1947.

Mr. Russell is a 1909 graduate in civil engineering of the University of Illinois, where he completed the full course in only two years. He is a member of Tau Beta Pi and Sigma Xi.

Upon graduation he took a position in the Kansas City Southern Railway, in which he gained experience in construction of terminal yards, paving, bridges, sewers, etc. This engagement was followed by an appointment as Office Engineer, and later, as Engineer-in-Charge of the Kansas City Sewer Division, which was then developing the basic plan for the present sewer system of the city. Mr. Russell left the employ of the city to engage in private consulting practice in Kansas City until the outbreak of World War I. As a reserve officer he served overseas with the 314th Engineers, 89th Division, attaining the rank of Captain.

His civilian career was resumed with the Sanitary District of Chicago, where he served as Assistant Engineer (Sewage Disposal) in connection with the design of various sewage treatment plants of the District. Return to private practice at Springfield, Mo., brought engagements to design a comprehensive sewage works project for the city of Springfield—including the largest sewage treatment plant in the state—and to make plans for 400 miles of state roads.

Since 1929 Mr. Russell has been in consulting practice in St. Louis, Mo., as President of the firm of Russell and Axon.

President Russell has contributed freely of his time and energy to various professional activities, and is at present on the lecturing staff at the University of Missouri, a member of the St. Louis County Planning Board, and a member of the Missouri Water Works Operators' Examining Board. A member of the Missouri Water and Sewerage Conference for more than twenty years, he has represented that organization in the Federation Board of Control for five years and was honored by the Conference in 1945 when he was named to receive the Kenneth Allen Award.

VICE-PRESIDENT EHLERS SERVES FEDERATION LONG AND WELL

The induction of V. M. Ehlers as Vice-President of the Federation in October climaxed a relationship of more than twenty years' standing, beginning with Mr. Ehlers' service on the "Committee of One Hundred" which planned the original organization of the Federation. Mr. Ehlers was a charter member of the Board of Control, on which he served continuously from 1928 to 1942.

His record of Federation committee activity bears witness to the value placed on his judgment and administrative ability. He has in the past held appointments to the Organization, Coordinating, Publicity and Executive Committees, and is presently a member of the Legislative Analysis Committee.

Mr. Ehlers is one of the nation's leading public health engineers, having held since 1915 the position of Chief Sanitary Engineer of the Texas State Department of Health.

Reviews and Abstracts*

Edited by

H. GLADYS SWOPE

Allegheny County Sanitary Authority,
4501 Center Avenue, Pittsburgh 13, Pa.

Field Test for Assessing Approximately the Quality of Effluents from Treatment of Domestic Sewage. BY E. E. JONES AND T. H. SUMMERS. *The Surveyor*, **105**, 299–301 (April 19, 1946).

Because of the absence of laboratory facilities in many military and other camps in Great Britain, a simple test was developed for the routine testing of quality of effluents from sewage treatment works. The test is performed by preparing various concentrations of the plant effluent and treating each with acid and potassium permanganate.

A field kit was designed to hold five 50 ml. low form Nessler tubes, a sample bottle, a bottle of acid, pipettes, mixers, and cleaning brush.

The test is performed by using four 50 ml. portions of sewage effluent in the Nessler tubes, numbered from 0 to 3. Tube 0 is used as a blank. To each tube 1, 2, and 3 are added 2 ml. of 25 per cent sulfuric acid and 2 ml., 4 ml., and 6 ml., respectively, of N/80 permanganate solution. The color is observed in 30 minutes and the character of the effluent determined by the following table, which also gives the range of oxygen absorbed values:

No. of Last Cylinder in Which Liquid was Colorless at End of 30 Minutes	Estimated Range of Oxygen Absorbed in 4 Hours at 26.7° C., p.p.m.	Character of Effluent
0	0–12.5	Very good
1	10.5–23.	Good to satisfactory
2	20.5–34.5	Unsatisfactory
3	31.5	Very unsatisfactory

RALPH E. FUHRMAN

Experimental Work at the Northern Outfall Works of the London County Council, 1940–1946—Part II. BY E. H. VICK. Paper * presented at a meeting of the Metropolitan and Southern Branch of the Institute of Sewage Purification, November 16, 1946. 10 pp.

This paper is a continuation of the wartime experiments with a view toward utilizing sludge as a fertilizer. Part II is concerned with the composting of sewage sludge with household refuse for use as a suitable fertilizer.

In the early experiments at the Southern Outfall Works, the pulverized refuse was mixed with sedimentary sludge in a concrete mixer, 1.22 parts of sludge being mixed with 1 part of refuse by weight. The mixture failed to ferment satisfactorily, but this may have been due to the cold weather (January).

The experiments were extended at the Northern Outfall Works where digested and activated sludge were available in addition to raw sludge, and compressed air was available for artificial aeration of the heaps of compost. The heaps were constructed 7 ft. by 4 ft. by 4 ft. high; those with aeration having two diffuser tiles spaced one ft. apart underneath the heap, connected to an air supply having a pressure of 7 lb. per sq. in. The heaps were laid out as follows:

Heap A. Refuse and raw sludge .... aerated
Heap D. Refuse and raw sludge ..... no air
Heap B. Refuse and activated sludge..aerated
Heap E. Refuse and activated sludge .. no air
Heap C. Refuse only ..... aerated
Heap F. Refuse only ..... no air
Heap G. Refuse and digested sludge .. no air
Heap Z. Refuse and screenings ..... no air

* A preprint.

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in THIS JOURNAL. Publications of public health departments, stream pollution control agencies, research organizations and educational institutions are particularly desired. Address such material: Federation of Sewage Works Assns., 325 Illinois Bldg., Champaign, Ill.

Chemical Compositions of Organics Used in Field Experiments, 1945

Manure	Dry Matter	As Percentage of Dry Matter				
		Total N	Amon. N	Total K_2O	Total P_2O_5	Loss on Ignition
Farmyard Manure	20.4	2.439	0.194	2.20	1.472	76.4
Refuse-Screenings Compost	58.2	1.276	0.122	0.50	0.878	40.1
Refuse-Sludge Compost	73.2	0.808	nil	0.44	0.591	32.5
Screened Dust-Reigate	85.5	0.504	nil	0.32	0.673	19.8

None of the aerated heaps showed a rise in temperature. Of the remaining heaps, heap Z produced by far the best results. Therefore, the remaining experiments were concentrated on a compost of refuse and screenings at a determined proportion of 1:1 by volume for the most satisfactory results. These screenings were produced by screening the raw sludge immediately after it leaves the sedimentation channels.

Further work indicated that the composts could be made by adding alternate one ft. layers of pulverized refuse and screenings to allow fermentation for one week. Then the mixture was placed in stacks about 10 ft. wide by 6 ft. high by 100 ft. in length, and allowed to mature for 3 months.

Similar composts were made with a sludge-refuse compost, but fermentation results were not satisfactory.

Various agricultural experiments were conducted by C. Bould of the Dept. of Agriculture, University of Bristol, on cabbage, potatoes, beets and mangolds to determine the relative values of refuse-screening compost, refuse-sludge compost, farmyard manure, screen dust-Reigate and a control. The chemical analysis of the organics is shown in the tabulation which follows:

Additional agricultural experiments were made on a straw-sludge compost, but no conclusive results were obtained.

The following conclusions were made on the agricultural experiments:

(1) Both sludge-refuse compost and screenings-refuse compost have appreciable manurial value.

(2) Screenings-refuse compost which appears to be more or less equivalent on a fresh weight basis to farmyard manure is somewhat superior to sludge compost.

(3) Production costs at an output of say 4,000 tons (long) per annum might be expected to be 8/-per ton. Operating on a considerably larger scale this figure might be substantially reduced.

(4) The results of the present experiments indicate not only an increase in the weight of the crop following application of the compost, but also an improvement in quality.

(5) The results were obtained on war-time refuse, from which a considerable proportion of organic matter had been salvaged. It may be anticipated that some improvement would result from the relaxation of war-time restrictions.

ROBERT P. LOWE

Sewage Purification in South Africa. BY H. M. DE VAAL. *The Surveyor,* **105,** 98 (February 8, 1946)..

This article is brief and general in nature.

Sewage purification in South Africa was begun about the year 1900. Early sewage treatment plants were established at several military camps during the Anglo-Boer war.

It is estimated that the total number of sewage treatment plants in South Africa is well over 100. This figure includes plants serving mines and institutions. Approximately 30 plants serve communities of 3,000 persons or more.

GERARD A. ROHLICH

Sewerage and Sewage Disposal in 1945 (British Isles). *The Surveyor,* **105,** 141–146 (February 22, 1946).

This article presents a general review of sewerage and sewage disposal activities in the British Isles during the year 1945.

The effects of six years of "upset and improvisition" during the war are gradually being overcome. Supplies of materials and labor are still low as is evidenced by the fact that loans sanctioned by the Ministry of Health to local authorities in England and Wales for disposal of waste products (refuse disposal, sewerage, and sewage disposal) totalled only £168,000 during the quarter ending December 31, 1945.

Research. Although no specific researches are discussed it is stated that a considerable amount of important research and experimental work has been carried out during recent years despite the difficulties in obtaining personnel.

Administration and Policy. At present, government attention is concentrated on creation of comprehensive river boards, and on a review of local government boundaries. River boards will be of service in seeing that all sewage works produce effluents of required standard of purity. Should the review of local government boundaries succeed in coalescing local government into units of reasonable size and adequate financial standing, then the employment of properly qualified men to administer sewage purification services will become possible. At present there is little collaboration between neighboring authorities. "In many cases certain sewage disposal works are operating with defective supervision and poor maintenance, while in the near vicinity there are other authorities having staff well qualified. . . ."

Sewerage. Present construction work is confined to urgent projects, such as priority housing.

Sewage Works Operation. "The continued shortage of suitable labor is still seriously handicapping operation and maintenance." Plants are showing the effects of inadequate attention during the war years. The attractive positions in industry are drawing men from the sewage plant operation field with the result that "it seems doubtful whether sufficient properly qualified men will be available to get the best out of sewage purification plants of advanced design."

Screening and Grit Removal. "Fine screening is rapidly dropping out of use. The normal practice is to reduce screening to the absolute minimum." Present tendency in design is to place screens in advance of de-gritting units.

Flocculation of Sewage. The article, "Controlled Septicity of Sewage" by W. Watson, is discussed. An abstract of this article appeared in *Sewage Works Journal*, **18**, 577–578 (May, 1946).

Sedimentation. Reference is made to the article "Research Relating to Sedimentation," by L. B. Escritt, *The Surveyor*, **104**, 299–300 (June 1, 1945). An abstract of this article appeared in *Sewage Works Journal*, **18**, 773–774 (July, 1946).

An appeal is made for more attention in research, design and operation, for final sedimentation, particularly that of filter effluents. "Inefficient humus removal is the cause of much trouble."

Biological Filtration. The interest in biological filtration in England is evidenced by the number of articles discussed. The following quotation is of interest:

"When considering American data, it is well to remember that many of their high-rate plants produce results which in this country would be regarded as only partial purification; most of our rivers are too small to stand ill-treatment. Allowance must also be made for the dilute nature of many American sewages, owing to the high water consumption in that country."

Sludge Treatment and Disposal. Composting of sewage sludge with straw or house refuse has attracted considerable attention.

The work of W. Parker at the West Middlesex Sewage Works on propulsion of road vehicles by sludge gas is discussed. Mr. Parker "does not appear to expect compressed methane to come into general use as a motor fuel . . . unless petrol prices increase."

Mention is made of the use of methane gas during the war in the manufacture of fire bombs. This "probably constituted the first instance of the successful use of sewage as a weapon of war."

Trade Effluents. Increasing importance of trade waste problems is stressed. The nature of the problem is evidently little different than that experienced in this country.

River Control. "In administration, undoubtedly the outstanding factor is the definite decision to establish river boards for the whole country, having comprehensive functions covering pollution preven-

tion, fishery protection, drainage, and, in certain circumstances, navigation."

GERARD A. ROHLICH

Sewer Maintenance. By J. M. RIDDET. *The Surveyor,* **105**, 167 (March 1, 1946).

This is a very well written, interesting article discussing the maintenance and repair problems of sewers in certain areas of Glasgow. Many of the sewers are at least over 100 years old.

The problems of sewer workers' ills are described with particular reference to the incidence of Weil's disease.

GERARD A. ROHLICH

Rochdale Kessener Brush Aeration Plant (Discussion at Northwestern Branch Meeting of Institute of Sewage Purification). *The Surveyor,* **106**, 85–87 (Jan. 31, 1947).

The original paper was prepared by D. H. A. Price and I. Withnell. See *The Surveyor,* July 5, 1946. (Abstract in *Sewage Works Journal,* **19**, 131 (1947).)

Gas liquor has been the major problem in the operation of this plant. This industrial waste reached the plant in "slugs." One "grab" sample had a 4 hour oxygen consumed value of 1,580 p.p.m. The authors indicated that the filters did not withstand the shocks of gas liquor as well as the activated sludge plant.

The authors disagreed with the contention that nitrates induce algae growths. They contended that a non-nitrified effluent was more likely to produce algae growths than was a nitrified effluent. However, H. Taylor in discussing this conclusion stated that there was a considerable body of experience to indicate that algae growths were promoted by nitrate and the fact that algae growths did not occur with increased nitrification meant that some inhibiting factor other than nitrate was present. H. Taylor also noted that when troubles due to nitrates were referred to, the growths were not in the plant effluent but in the water which received the effluent. He further stated that most operators found that when an increase in nitrates occurred during the summer, rising of humus sludge took place particularly in the case of filter plants.

PAUL D. HANEY

Laying Sewers Across Valleys. By L. B. ESCRITT. *The Surveyor,* **106**, 75–77 (January 31, 1947).

When it is necessary for a main sewer to cross a river, valley, railway cut or other depression the engineer has the choice of several courses of action. In some instances pumping may be the solution. In others it may be possible to change direction and avoid the depression. Other alternatives are carrying the sewer above ground on a bridge or constructing an inverted siphon.

The principal problems involved in above-ground construction are structural, and careful consideration must be given to the support of the pipes and to allowances for expansion and contraction. Exposed metal pipes should be protected against corrosion. Internal protection is desirable in metal pipes which do not permanently run full. Pier foundations should be carried to firm bearing and the piers should be designed to withstand wind pressure. Pipes may be carried on lattice girders where the spans are too great for the pipes themselves to take the bending moments. Where large sewers are carried at considerable height above ground level and appearance is a major factor it may be found advisable to go to the expense of constructing a brick or masonry aqueduct.

The main difficulty with inverted siphons is silting and this is caused by the fact that these siphons have to be made large enough to accommodate the maximum rate of flow with the result that at normal flow self-cleansing velocities are not obtained. Furthermore such velocities are higher for siphons than for normal sewers because the rising leg of the siphon provides a gradient up which the particles must be carried. Difficulties in siphon design increase when there is little fall available and when the maximum rate of flow greatly exceeds the average rate. Designs then have to be carefully considered and two or more siphons provided to accommodate the fluctuating flow. (Examples of siphon design are given.)

One method which has been used to insure self-cleansing conditions is to provide a sewage flush tank at the head of the siphon. This insures that the sewage passes through the inverted siphon in

periodic doses at a high rate of flow. However, the operation flush tanks require considerable head which may not be available.

Because inverted siphons operate under pressure they should be constructed of strong materials such as cast iron, steel tubes, reinforced concrete, etc., according to size. Attention should be given to the construction of manholes at top and bottom ends. Siphons should have bellmouth entrances and well designed outlets to reduce transition losses. When two or more siphons are used arrangements should be made that will permit flushing each siphon independently. Cleanouts should be provided at the lowest point of each siphon. Long siphons should have cleanouts at intervals of not exceeding 360 ft. to make rodding possible. Water flushing arrangements should be provided.

PAUL D. HANEY

Sewerage and Sewage Disposal in 1946. *The Surveyor,* **106**, 131–133 (March 7, 1947); 149–151 (March 14, 1947), 163–165 (March 21, 1947).

One of the important factors contributing to the impetus given to research work in the sewage works field has been the changed attitude of local authorities toward research programs. These authorities are beginning to realize that research pays.

No very striking change in administrative practices occurred during 1946, but there is a general feeling that in many instances local authorities could, with advantage, cooperate more closely. On several occasions the policy of operation on an aerial basis has been recommended for dealing with problems of sewage purification which are likely to arise in rural districts. The installation of public water supplies in rural areas with its natural corollary of sewage disposal has not yet proceeded far enough to indicate whether this policy will be followed.

General policy in sewerage is toward separate or partly separate systems. The overflows from combined sewers have been responsible for much river pollution. Modern opinion leans toward the view that once domestic sewage or industrial waste has entered a sewer its only destination should be a sewage treatment plant.

On a nation-wide basis there is no doubt that the operation of sewage disposal works is becoming more efficient. However, poor salary scales and conditions of service make it difficult to obtain qualified technical personnel.

The most pronounced trends in sewage works design appear to be toward intensification and mechanization. Increased mechanization is apparent at nearly every stage of the treatment process. There also seems to be a tendency toward reduction of the time lag between discovery and application. This is justified by the fact that much present day experimental work is thorough and the results may, therefore, be applied with some confidence to full scale works.

Measures taken to protect sewers and sewage disposal works against damage from settling due to mining activities have met with some success.

Both in screening and grit removal the tendency is to remove less solid matter than formerly. Fine screening is now unusual and a genuine attempt is made to design grit chambers which remove nothing but grit.

Sedimentation tanks which require manual operations for sludge removal are becoming unpopular. There is also a move toward reduction in the theoretical detention time provided in sedimentation tanks. The present-day average detention time is six to eight hr. on the basis of dry weather flow. The use of chemicals to assist sedimentation is still restricted to special cases, but their use may be justified when it is essential to give relief to an overloaded plant and when stream flow is sufficient to make full treatment unnecessary.

Some work has been done on mechanical flocculation and more is in progress. In order to justify itself mechanical flocculation has only to show a modest improvement over plain sedimentation since the costs of installing and operating it are not great.

Of the newer methods of trickling filter operation, recirculation of the effluent is the one receiving the most attention. Varying the rate of recirculation roughly in inverse proportion to the flow of sewage offers possibilities of economy in design and efficiency in operation.

Experiments with DDT for the control of filter flies are under way.

The variation in efficiency of trickling filters may be due to the growth, distribution and disintegration of the biological films on the filter media.

Of particular interest in the activated sludge field is the "picket fence" sludge thickener employed at one plant. At activated sludge plants where thickening of the waste activated sludge is desirable this method can remove about 80 per cent of the water in a thickener having a detention time of two hours. Another interesting development has been the installation of a new dome shaped diffuser at the Manchester plant.

Digestion followed by dewatering on open drying beds is recognized as the standard method of sludge treatment but there is a willingness to employ more compact methods if they can be proved effective and not too expensive. There is indirect evidence that the suggestion that it might be profitable to introduce an aerobic stage between anaerobic digestion and the drying beds merits investigation.

Considerable quantities of sludge are still dumped into the ocean but dumping on land is much less common than it was 10 years ago due to the demand for sludge as a fertilizer. Incineration has never had wide appeal but reports on the usefulness of dried sludge as a fuel may put a different complexion on this matter particularly in view of the need for fuel economy. The present acute fuel shortage supports the case for the wider use of sludge gas. Furthermore pure methane can be prepared from sludge gas and this pure gas can be used as a starting point for sythesizing various organic compounds. (*Abstractor's note:* See *Sewage Works Journal,* **19**, 700 (July, 1947).)

Significant information in connection with sewage chlorination is the report that free chlorine in a concentration as low as 0.3 p.p.m. is appreciably toxic to fish life. Chlorine appears to be especially toxic in the case of sewage plant effluents which contain thiocyanate derived from gas liquor or other chemical wastes. Experiments have shown that liquids containing nontoxic concentrations of thiocyanate become strongly toxic after chlorination, the period of survival of the fish diminishing as the dose of chlorine increases.

There are indications that in industrial areas industrial waste pollution is coming to be regarded as a much greater threat than domestic sewage to aquatic life. One investigation has demonstrated that chemical poisoning of a stream may remain undetected by the type of analysis normally carried out on stream waters but be quickly discovered by biological investigation. It was concluded that both methods should be employed in stream investigation.

The projected rivers boards with comprehensive powers and duties have not yet been established; however, it is certain that they will ultimately be created.

PAUL D. HANEY

Limestone Used to Neutralize Acid Wastes. BY A. L. REIDL. *Chemical Engineering,* **54**, 100–101 (July, 1947).

Upflow beds of limestone combined with an aeration system have proved to be an effective means of neutralizing the wastes from acid dipping and plating works at the General Electric Company's Philadelphia works. The neutralized effluent is recirculated and in conjunction with an eductor is used to lift the raw waste into the treatment plant. This arrangement avoids the use of expensive acid pumps. The treated effluent is discharged into the Schuylkill River.

Limestone beds are advantageous for the treatment of acid wastes because they are simple to construct and require little maintenance.

Under present conditions the Philadelphia plant uses about 60,000 gal. of various acids annually. About 40,000 gal. of water are used annually for washing. The wastes from the acid dipping and plating operations usually have a pH of 3.9 to 4.4 but the pH may be 1.9 or less when spent acids are being dumped. The average rate of flow of all wastes from dipping, washing and rinsing activities is approximately 200 g.p.m. Various samples of the raw waste indicated a composition as follows: Floating material (grease, oil, etc.), 50–500 p.p.m.; sediment, 600–2,500 p.p.m.; pH 1.9–4.4.

Preliminary tests on a small scale indicated that to keep the 18 in. to 24 in. limestone neutralizing beds clear of slime, sludge, etc., a rate of flow between 40 and 50 g.p.m. per sq. ft. is necessary. Checks were made to determine the effectiveness

of the bed and the necessary dilution of the raw waste to insure an effluent pH of not less than 5. Acid waste going to the bed with a minimum pH of 3 was easily brought to pH 5. Values lower than 3 resulted in a deposition of calcium sulfate on the limestone.

A neutralized effluent of pH 5 could be brought to pH 6 by agitation for a few minutes to liberate carbon dioxide.

In an 8 hr. period with a raw waste flow rate of 200 g.p.m. and containing 150 to 200 gal. of acid waste the consumption of limestone averaged between 5 and 10 cubic feet. The limestone media used varied in size between 2 and 3 mm.

For best results the beds should be constructed to give uniform flow over the entire area without channeling.

The design finally adopted involved the use of a three compartment skimming and settling tank and two upflow limestone beds. Effluent is recirculated the recirculation ratio being approximately 2:1.

PAUL D. HANEY

Waste Pickle Liquor. BY RICHARD D. HOAK. *Industrial and Engineering Chemistry,* **39**, 614–618 (May, 1947).

The quantity of iron and steel produced annually in the United States from which the film of oxide must be removed before the finishing operations can be successfully applied has increased; for tin, terne and black plate from about 1,000 tons in 1891 to 4,328,000 tons in 1941; for galvanized products to 5,746,000 tons in 1941. Most of this tonnage was surface-cleaned by "pickling" in solutions of the acids: sulfuric, hydrochloric, nitric, hydrofluoric, and phosphoric, individually or in different combinations; more than 90 per cent was pickled in sulfuric acid. Hence, this paper deals principally with spent sulfate pickling liquors. The approximate compositions of the waste liquors from batch picklers and continuous picklers are by weight respectively, as follows: from 0.5 to 2 per cent and 4 to 7 per cent free sulfuric acid; from 15 to 22 per cent and 14 to 16 per cent ferrous sulfate. The total annual volume of waste pickle liquor made in this country has been estimated to be in excess of 600,000,000 gal.; less than 4 per cent of it could supply all the copperas, $FeSO_4 \cdot 7H_2O$, for which markets are available. The disposal of the spent liquors has been one of the steel industry's serious problems for more than fifty years. Methods of disposal mentioned are: discharging the untreated waste liquor into water bodies, sanitary sewers, lagoons and slag dumps. Also pretreatment with lime and discharging the resulting slurry into lagoons, or into settling basins from which the neutralized and clarified effluent flows into a receiving water way and the sludge is transported to a suitable dump.

Several of the more important of the eighty-odd processes proposed for the treatment of waste pickle liquor for recovery of byproducts are briefly described and their relative advantages and disadvantages are stated under the following headings: copperas, copperas and free acid, ferrous sulfate monohydrate, ferric sulfate and sulfuric acid, iron oxide and sulfuric acid, electrolytic iron, iron powder, iron oxide pigments, construction material (Ferron), ammonium sulfate, and miscellaneous inorganic compounds. Most of these proposed processes have not passed beyond the laboratory stage; a few have been subjected to pilot plant investigations. There are several plants in operation for recovery of copperas from the spent liquors.

The researches on waste pickle liquors conducted since 1938 by the American Iron and Steel Institute's Industrial Fellowship at Mellon Institute are reviewed in somewhat more detail and include eight major investigations.

(1) It was discovered that ferrous sulfate could be used in place of gypsum to regulate the setting time of Portland cement. Utilization of copperas, obtainable from spent pickling liquor, for this purpose would involve satisfactory results in service tests of this somewhat darker colored cement, amendments to the A. S. T. M. specifications for cement, and a process for recovering the copperas at a cost whereby it could compete with the price of gypsum.

(2) A new process (Differential Solubility) was developed using acetone to separate about 95 per cent of the copperas from the waste pickle liquor and recover most of the free sulfuric acid in a condition suitable for reuse in the picklers.

This process requires the use of a volatile, inflammable solvent and to be economically feasible the recycling of 99.5 per cent of the acetone.

(3) A method was devised for the preparation from spent pickling liquor and other chemicals of a 60 per cent ferric chloride solution and a fairly pure sodium sulfate. The method involves a number of unit operations, but might have application in localities where the spent liquor was readily available and there were near-by markets for the ferric chloride and sodium sulfate.

(4) The shortage of manganese, essential for the production of steel and certain alloys, in the early days of the war led to the development of a process in which low grade manganese ores were ball-milled with waste pickle liquor, the clarified extract was treated with calcium chloride, the precipitated gypsum filtered off and lime slurry added to the filtrate. A concentrate containing 60 per cent or more of manganese was obtained; also the two by-products of low value, gypsum and iron oxide. However, most of the suitable ores are mined at great distances from the centers of steel manufacture.

(5) Magnesia of 91 to 94 per cent purity was prepared by treating waste pickle liquor with calcium chloride, filtering out the gypsum formed, removing the iron from the filtrate with dolomitic lime slurry, then adding more dolomitic lime to precipitate the magnesia. The calcium chloride brine was concentrated and recycled. Evaporation of large quantities of wash waters is a disadvantage.

(6) Ammonium sulfate of good quality and a magnetic oxide which separates readily from the solution have been prepared after extensive study of the physico-chemical factors involved when waste pickle liquor is treated with ammonia. Based on results of small pilot plant investigations this process appears to be sound and further developments are in progress.

(7) Since several steel mills, presently, and probably most of the smaller mills in the future will have to depend on neutralization processes for the treatment of their spent pickling liquors, extensive researches have been conducted on the comparative reactivity of several neutralizing agents, especially different kinds of limestones and limes. Much new and useful information has been obtained. Dolomitic limestones were found to be unsatisfactory for treatment of waste pickle liquor; for best results with high calcium limestones they should be pulverized to approximately 200 mesh size. Both high calcium and dolomitic limes gave good results, but a slight excess of the latter was necessary to complete the reactions. In some localities the use of dolomitic lime would be economically advantageous. Aeration during neutralization was found to increase the rate of reaction and to produce a much more rapid settling of the suspended solids. A split limestone-lime process has been developed and where high calcium pulverized limestone is available at approximately 56 per cent of the cost of calcium oxide equivalent as quick lime, economies in neutralization of waste pickle liquor can be made by application of the split-type treatment. One steel company has already installed this process.

(8) Preliminary investigations on the treatment of stainless steel spent pickling liquors with high calcium lime have shown that a good quality of calcium nitrate, useful as a fertilizer, can be obtained; also a slurry of metallic oxides which could be sintered for recharging to the furnace. The relative advantages and the objectionable features of the processes are briefly discussed. Researches on some of the more promising processes are being continued. A number of references are given.

W. W. HODGE

Acid Mine Drainage. By J. RAYMUND HOFFERT. *Industrial and Engineering Chemistry,* **39**, 642–646 (May, 1947).

This paper deals with the acid drainage from coal mines, drift, shaft, and "strip" mining; also with the silt (mainly from anthracite breakers); materials which have for years polluted many streams. The acid mine drainage appears to be formed by a *"natural"* reaction when the coal is exposed to air and water and has been accepted as an unavoidable evil resulting from the necessary mining of the coal which in 1944 amounted to 620,000,000 net tons of bituminous coal and 63,701,350 tons of anthracite and gave direct employment to 460,600 persons. Although many coal mines discharge alkaline water, from most

of them there issues acid-impregnated mine water the total volume of which is unknown, but is enormous. The acid mine drainage discharged during 1932 from the coal mines in West Virginia alone has been estimated at an average of about 168,349,000 gal. per day. The volume and acidity vary from mine to mine, but a probable average is 1,000 gal. per day per acre of mined-out area. Abandoned coal mines usually "make" the most acid waters and continue to do so for many years. The concentration of the acid ranges from less than 100 to nearly 50,000 p.p.m., with typical values of about 100 to 6,000 p.p.m. as sulfuric acid. Other substances usually present are: iron sulfate 10 to 1,500 p.p.m.; aluminum sulfate 0 to 350 p.p.m.; and manganese sulfate 0 to 250 p.p.m. (the latter three reported as oxides). Estimates made by the U. S. Public Health Service and U. S. Army Engineers placed the quantity of acid carried by the Ohio River and its tributaries prior to the program for sealing abandoned coal mines which started in 1933–34, at the equivalent of 2,500,000 tons of concentrated sulfuric acid per year. Of this amount, 47.4 per cent was credited to abandoned mines, 7.2 per cent to marginal mines, and 44.75 per cent to active mines. The sealing of abandoned coal mines in Pennsylvania up to 1938 was estimated to have reduced the acid discharged by 177,000 tons per year, but there was still being discharged from the coal mines 1,075,000 tons of acid per year. Mine drainage presents numerous anomalies and to date no general relation has been proved between the per cent of sulfur in the coal in a mine and the acidity of the drainage from the mine.

The source of the acid in mine waters is the sulfur bodies in or associated with the coal measures, principally the iron sulfides (FeS_2) pyrites and marcasite which react with air and water to form the sulfates found in the mine drainage. The equations given to indicate the probable chemical reactions involved are as follows:

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2FeSO_4 + 2H_2SO_4, \quad (1)$$

$$2FeSO_4 + \tfrac{1}{2}O_2 + 2H_2SO_4 \rightarrow Fe_2(SO_4)_3 + H_2O + H_2SO_4. \quad (2)$$

Combining the two reactions in order to determine the final outcome of the oxidation,

$$4FeS_2 + 15O_2 + 2H_2O \rightarrow 2Fe_2(SO_4)_3 + 2H_2SO_4. \quad (3)$$

Finally, when other entering streams bring the acid concentration down sufficiently, the ferric sulfate in turn hydrolyzes,

$$Fe_2(SO_4)_3 + 6H_2O \rightarrow 2Fe(OH)_3 + 3H_2SO_4. \quad (4)$$

These equations show how the end products may be formed, but the mechanism of the reactions has not been fully investigated and there is evidence that bacterial action may play a role in the formation of the sulfates and of the final products.

The effects of acid mine drainage on the receiving streams are discussed. The sulfuric acid and soluble sulfates of iron and aluminum which hydrolyze to form acid cause hardness of the water, greatly increase the rates of corrosion of rivercraft, lock gates and other steel structures, may make the river unfit for watering stock, and make it very expensive or impossible to satisfactorily treat the river water for use in municipal or industrial water supplies. Sudden changes in stream flow and acidity may destroy the bacterial film on filters upon which much of the safety of the water for potable purposes depends, unless the waterworks man "knows his river" and acts quickly and correctly. If a river also receives domestic sewage the acid mine drainage holds this organic matter without biological action and often leaves the solids mixed with other sediment on the stream bed. When the acid concentration is sufficiently diluted by freshets or down stream by inflowing neutral or alkaline tributaries the bacteriostasis ceases and the stream may become little more than an open running septic tank. The iron compounds frequently color the stream, its banks and bed yellow through orange red to reddish brown and may form sludge deposits.

The corrective measures proposed are outlined and their shortcomings stated. To date there is no recognized practical method of treating this acid mine drainage pollution. If treated with limestone, the calcium sulfate formed on the surfaces of the stone soon stops the neutralizing action. For every ton of coal mined in

Pennsylvania an average of about ten tons of water must be disposed of, hence the capital cost for construction of a treating plant, even if limestone was a satisfactory reagent, would be excessively high. The proposition of obtaining usable by-products was extensively investigated in a large neutralization plant, at the Calumet Mine in Pennsylvania. It ceased operations after a few years, principally because of lack of markets for the by-product iron oxide and the high cost for disposing of the large amounts of sludge which was "too thick to pump and too thin to shovel." Even if the process had been economically feasible the resulting water would be highly mineralized and expensive to treat or soften for domestic, power plant or industrial uses.

The one present method which offers hope for abatement of stream pollution by acid mine drainage is the sealing of abandoned mines so as to exclude air from entering the mine and providing a trap outlet through which the water in the mine can readily flow out. Ground plan and vertical section drawings are given of one form of typical mine seal; also one picture of the outlet works of a sealed mine. Mine sealing cannot be applied to active workings in mines because large volumes of fresh air must be constantly supplied to the working faces for the safety of the miners. It is hoped that mine sealing can be applied to some of the mined-out areas of active mines, but this involves problems of mining laws, prevention of the formation of explosive mixtures in "gassy" mines, and other practical questions, including economics. Other methods proposed as useful palliatives to minimize the evil effects of acid mine drainage until a real solution is found are: (1) multiple-use dams to increase dry weather flows; and (2) diversion of acid drainage from clean to already polluted streams, as provided for by recent legislation in Pennsylvania.

The great increase in recent years in "strip" or open-pit mining of coal has necessitated a new type of sealing. To protect streams the sulfur-bearing refuse, coal, bone, etc., should be segregated and covered over with selected material, well compacted and graded to shed rainfall and minimize the percolation of water and air through it. Also, the exposed coal face or "high-wall" should be back-filled to exclude air. Another method is to form lakes in the pits thus drowning out the exposed coal and stopping its oxidation. The danger from stripping operations lies in part in the insidious time lag between the mining and the appearance of acid drainage.

The most important step is to find a practical cure for the ills of acid mine drainage and fortunately fundamental research is now going forward. The State Health Department and the Sanitary Water Board of Pennsylvania have two Fellowships in operation at Mellon Institute of Industrial Research in Pittsburgh, Pennsylvania. One of these deals with the effect of acid mine drainage on sewage and other wastes discharged to streams, the other with the major problem of the mechanism of, and means for minimizing or preventing, the formation of the acid mine water. Also, for the past several years, Bituminous Coal Research, Inc., has sponsored a Fellowship conducting fundamental research on the acid mine drainage problem at the Engineering Experiment Station at West Virginia University. Considerable knowledge has been obtained on the properties of and probable mechanism of formation of the acid mine water; some previously proposed hypotheses have been found to be untenable. Valuable work has been done in developing more rapid, yet acceptable testing and analytical procedures for this type of industrial waste, and further evidence has been obtained on the possible role of bacteria in the production of acid mine water.

The control of silt has been insisted upon in recent years by the Pennsylvania Sanitary Water Board and many collieries have already stopped the discharge of silt into streams. In 1926 geologists estimated there were 900,000,000 tons of silt and culm in the Schuylkill and Susquehanna Rivers. As of 1936 the U. S. Army Engineers estimated there were 24,000,000 cu. yd. of silt and culm in the Schuylkill River above the Fairmont dam at Philadelphia, with a 650,000 ton annual influx. In the 1943–44 twelve-month a central generating and a central steam heating plant in Harrisburg, Pennsylvania, together burned 230,330 tons of this river coal. Today the coal washeries are gradually going out of business and the days of

blocked sewers and silt-filled stream channels are passing. By the installation of properly designed silt sedimentation basins, of mechanically cleaned clarifiers or froth flotation plants for removing minus 200-mesh material, effluents of relatively low or almost zero turbidity are being obtained. One company's installations serving three collieries are reported to have cost over $1,500,000. Stoppage of silt discharge is well in hand and removal of silt from the most heavily silted streams in the Commonwealth has begun.

The author expresses the hope that, through similar cooperation between coal operators, public officials, and research workers, a way will be found to stop the gross pollution of acid mine wastes.

W. W. HODGE

Pulp and Paper Industry. By L. F. WARRICK. *Industrial and Engineering Chemistry*, **39**, 670–676 (May, 1947).

The importance of abundant supplies of suitable quality water for use in pulp and paper mills is stated. A brief historical résumé traces the efforts made to find ways and means for taking care of the objectionable wastes from the mills: initially by individual companies; next by regional groups, such as the Wisconsin sulfite pulp manufacturers; and now by the industry-wide program of the National Council for Stream Improvement (of the Pulp, Paper and Paperboard Industries), Inc., begun in 1944. The general problem in abatement of pollution by pulp and paper mill wastes is discussed. The quality of effluents discharged should be considered in relation to uses of these waters for drinking and domestic purposes, power production, propagation of fish, oysters and other aquatic life, agricultural, recreational and other purposes. Three major objectionable properties of pulp and paper mill wastes are: (1) fibrous wastes have formed sludge deposits in the receiving streams which interfere with spawn and spawning of fish, entrap organic matter which decomposes, especially in warm weather, forming gas which creates offensive conditions and often large portions of the sludge are carried to the surface by the gas bubbles; (2) high oxygen demand which depletes the dissolved oxygen in the stream thus producing nuisance conditions, bad odors, and fish killings; (3) some of the wastes may contain or react to produce toxic substances which destroy aquatic life and endanger the domestic, municipal, and agricultural (for watering stock and for irrigation) water supplies. Specific cases of serious pollution and some remedial measures are described. At one mill the condition of the receiving stream was much improved by; installation of machines to reduce fiber losses, providing for the sulfite pulping waste, a storage pond having a cascade spillway for aeration of the wastes to decrease their rapid absorption of the dissolved oxygen in the stream, and addition of storage water to increase the dry weather flow of the river. Mechanical aeration of another stream overloaded with sulfite waste was started in 1945 and produced beneficial results. This is an ameliorating method for supplementing the content of dissolved oxygen in the river during periods of low flow or other emergency conditions pending acceptable means of abating pollution at its source.

Mill effluents are broadly classified into: (*a*) chemical pulping wastes; and (*b*) white water (fiber) wastes. Pulping processes discussed under (*a*) are: sulfite (acid); sulfate (alkaline), de-inking, rag, and groundwood; under (*b*) wastes from paper and paperboard mills. The chemicals used and successive unit operations applied in these processes and for several methods for treatment of the spent liquors are outlined.

In the sulfite pulping process about 50 per cent of the weight of the wood is in soluble waste products and they amount to about one ton for every ton of sulfite pulp made. These waste materials are discharged in 2,500 gallons of spent liquors which normally contain around 10 per cent of solids, mostly lignin and carbohydrates. Quantities and compositions vary according to the woods used and method of cook. Data for pulping of spruce and poplar are given on a 10 per cent solids basis in percentages, respectively, as follows: lignin 4.6 and 3.7, carbohydrates 2.3 and 3.2, sulfur dioxide combined with lignin 1.7 and 1.6; the other constituents are proteins, resins, fats and calcium oxide combined with lignosulfonic acid. Procedures for solution of the

sulfite waste problem have varied all the way from changing the principles of the process of sulfite pulping to ponding or lagooning the wastes—and from utilization to disposal of the liquors.

Utilization processes briefly discussed include: the Howard process for production of vanillin, plastics and other products, but which leaves the carbohydrates and other materials of high oxygen demand in the effluent. Studies conducted by the Sulphite Pulp Manufacturers Research League lead to the utilization of the spent liquor as a road binder, a binder for coal briquettes, for manufacture of adhesives and various other products. A biological method for production of fodder yeast has been worked out by which the oxygen demand can be reduced 60 per cent and the remaining lignin easily separated. One such commercial scale plant has been installed at a Wisconsin sulfite mill. Considerable has been accomplished in the long range research program on waste lignin utilization being conducted by the Institute of Paper Chemistry. One of the products is ethyl vanillate which offers promise of wide use as a food preservative. The production of ethyl alcohol from sulfite waste liquor has been investigated for many years. One plant is in operation in Ontario and another in Washington. The process is economically feasible in Scandinavia and Germany because of the higher price of alcohol. From the standpoint of stream improvement the fodder yeast process appears more promising since it utilizes both the fermentable and non-fermentable sugars in the waste liquor.

Applications of sewage treatment methods, especially the trickling filter process, to sulfite waste liquor were investigated by the League and more recently on a pilot plant scale by the National Council for Stream Improvement. Results showed the oxygen demand of the liquor can be substantially reduced if the proper nutrient materials are added, but further research is necessary before the trickling filter can be satisfactorily applied for treatment of spent sulfite liquor. Experiments in evaporation and burning of calcium-base sulfite liquors have been unsuccessful.

Of outstanding importance is the installation on a mill scale at Longview, Wash., of a pulping process in which magnesium replaces the usual calcium base of the cooking liquor. The waste liquor is concentrated to about 45 per cent solids and then burned in boilers for its fuel value and the base is recovered for making new cooking liquor. Efficient chemical recovery is necessary for satisfactory economies of the process.

A few sulfite pulping mills have partially or entirely solved their individual problems by producing from the waste liquors: adhesives, ingredients for hardening cements, vanillin, plastics, insecticides, fertilizers, and materials for use in the manufacture of dyes, in electroplating, in emulsions, in tanning, etc. Since one large sulfite mill could in one day's operation produce enough waste liquor to take care of the annual needs of this country for some of these products, such utilization is not very encouraging from the point of view of stream improvement.

In the sulfate (alkaline) or kraft pulping process a recovery system is now an integral part of the mill. Efficient recovery of chemicals is attained by concentrating the strongly alkaline liquors, then burning them in incinerators. The recovered chemicals are used in making new cooking liquor. Some losses which contain polluting materials occur in the black liquor, final pulp washings, condensate from evaporators, digester degassing condensates, and blow down condensate from the digesters. However, the effluents from these mills have much lower oxygen demand than sulfite waste liquors. Some of these wastes contain toxic materials; also produce objectionable odors. Stream improvement necessitates control of mercaptans, turpentine, sulfides, disulfides, and methyl alcohol found in the losses mentioned. Recent installations for turpentine recovery (1 to 3 gal. per ton of pulp) remove a major source of toxic material. Tall oil, skimmed from the black liquor, is now reclaimed in most mills for use in the manufacture of soaps and paints; if not recovered it should be burned to avoid pollution. The large quantities of lime sludge produced in sulfate and kraft mills are detrimental to fish and aquatic life if discharged to streams; hence most mills dispose of the sludge by recovering it for reuse in the process, lagooning it or by vacuum filtration with subsequent utilization as agricultural lime.

De-inking wastes contain ink, coloring materials, glue, rosin, dirt, paper-clay or filler and some fiber; hence are important from the pollution point of view. Old paper stock may contain 5 to 50 per cent of clay and treatment involves a difficult problem of solids disposal. One mill producing 60 tons of finished paper per day had to dispose of 1,000 tons of solids every month in keeping its wastes out of a stream. Lagooning has met with some success, but odor control is a problem.

In the pulping of rags for high grade bond and writing paper the coffee colored strongly alkaline spent cooking liquor and wash water amount roughly to 500 gal. per ton of pulp. This waste has a high oxygen demand, but the small volume gives the waste a comparatively low oxygen demand per ton of product. Where possible, the treatment of this waste along with municipal sewage should be considered.

In the groundwood process about 90 per cent of the weight of the wood is recovered as pulp. The wastes are mainly fibrous and have a relatively low oxygen demand.

In the paper and paperboard mills the installations in recent years of "save-alls" have recovered much usable fiber and contributed substantially to stream improvement. In many mills where there are few changes in product, colors, or other special conditions, the use of closed or partially closed systems has resulted in substantial savings. The closing of board mill white-water systems has increased the problem of slime control and necessitated the addition of anti-slime materials in the water. Careful control in applying phenol containing anti-slime compounds is necessary to avoid imparting objectionable tastes to downstream water supplies. Suspended solids in board mill wastes are being removed by settling and precipitation systems. Such solids as cannot be reused in the mill may have to be disposed of in lagoons to abate stream pollution.

The importance of having and using facilities for accurate measurements of flow of effluent wastes and of receiving streams; also of proper sampling in proportion to flow are emphasized. The results of the extensive 1946 survey of wastes at 68 Wisconsin pulp and paper mills are tabulated together with some data for 1945. The mills are grouped into 11 classes and data are given for individual mills and the averages for each class. In another table the average losses for various types of mills in Wisconsin for 1945 and 1946 are compared. Both tables present on the per ton product basis: gallons of wastes; pounds of solids, fixed suspended, volatile suspended and total soluble; fiber loss in per cent of production and 5-day B.O.D. population equivalents. Large differences were found in the volumes, compositions, fiber losses and B.O.D.'s of the wastes from mills, even in the same classification. A few of the average 1946 data per ton of product are as follows: gal. of waste from 2,302 for groundwood to 64,838 for kraft pulp; lb. of volatile suspended solids from 0.6 for groundwood to 188.2 for rag and de-inked pulp; 5-day B.O.D. person equivalents from 20 for groundwood to 2,857 for sulfite pulp. Estimates of loss in dollar per day due to unrecovered fiber vary from $0.77 for a groundwood mill to $417.68 for one of the kraft pulp mills. A graph based on the 1946 survey shows for paper mills and sulfite pulp mills the distribution as volumes of wastes vs. fiber loss per ton of product. Thirty-six of the data are below the 2 per cent line and eleven between the 2 and 5 per cent lines. The wastes utilization and stream improvement program being conducted in Wisconsin has the objective of reducing volumes of water required per ton of product below 20,000 gal. and fibrous waste losses below 1 per cent of production.

Several illustrations of wastes treatment plants and samplers and a number of references are given.

W. W. HODGE

Conservation of Natural Resources. BY W. E. HOWLAND. *Proceedings* of the Second Industrial Waste Conference, pp. 11–19, Purdue University, 1946.

The depletion of our natural resources, through both direct waste and unwise rapidity of utilization, is a matter for grave concern.

Sanitary engineering activity, in an important sense, is conservation: the conservation of health and the conservation of water resources.

Conservation means "the economic utilization; avoidance, insofar as is possible,

of waste but, nevertheless, actual use of the good things that nature provides." Since engineering has been defined as "economic utilization of the materials and forces of nature for the benefit of man," all engineers are conservationists.

Civil engineers may contribute to conservation by:

(*a*) Planned research;
(*b*) The use of more refined methods of structural and hydraulic analyses;
(*c*) The use of "guides" or special methods and tricks to find the low point on the cost curve in preliminary design; and
(*d*) Studying a large number of possibilities for accomplishing a given result in an effort to find the scheme of least cost.

In judging economy the criterion should be least total net cost. All costs and all benefits must be considered. While private enterprise projects must give promise of both interest and monetary return for justification public projects may be justified by intangible benefits alone. Although there is this difference, the author states "I think it is fair to say that no project, public or private, can be justified that does not ultimately prove economical to society as a whole when all the costs and benefits, both tangible and intangible, are properly weighed." Thus current methods for evaluating private projects may need to be revised in the interests of conservation. The author suggests that government subsidy "through revision of taxes or otherwise" may assist industry in making economic choices that will be wiser, in the long run, for all concerned.

ROY F. WESTON

Industrial Wastes—What are They? By GEORGE E. SYMONS. *Proceedings* of the Second Industrial Waste Conference, pp. 20–27, Purdue University, 1946.

"Waste, in its strictest sense, is the nonuse, spoilage, loss or destruction of either matter or energy that is usable by man or other living creatures."

This definition would exclude some materials now classified as industrial wastes and, considering the economics of usability, would lend itself to different interpretations depending on the view point.

A proposed definition of industrial waste that can be used by the industrialist, the conservationist, the sanitary engineer, the medics and the public is as follows: "Industrial waste is that material or energy discarded intentionally or unintentionally by industry during the production of some useful product, regardless of whether that material is discarded to the atmosphere, to the land or to the waters of the earth, and regardless of whether or not the discarded material has any present or potential value, or any effect on natural surroundings."

Wastes discharged to the atmosphere may cause acute local problems. The use of precipitators, washers, cyclones and ozonizers may solve these problems.

Wastes disposed to water are classified as inorganic, organic and mixed. Various industrial wastes are classified. Waste energy as heat is classified separately.

The author points out that some industries discharge valuable materials without being aware of the magnitude of their loss. Others discharge materials causing considerable damage without being aware of the damage that is being inflicted and in some cases being unable to get employees to admit such discharges.

By-product recovery, including water, may be economically feasible in some cases but not every waste contains economically recoverable material.

Industry must be prepared to pay a fair share of treatment costs where wastes are discharged into a municipal sewage-disposal system and must accept waste treatment as a legitimate production cost to preserve our natural resources.

ROY F. WESTON

Grease Recovery in the Meat Packing Industry. By E. N. MORTENSON. *Proceedings* of the Second Industrial Waste Conference, pp. 28–39, Purdue University, 1946.

The amount of grease entering the sewers in a meat packing plant can be appreciably reduced at the source by common sense and good housekeeping. Good practice in the rendering section will do more toward reducing the loss of grease to the sewers than can be accomplished by careful handling in all other departments.

Properly designed grease interceptors are necessary regardless of the attention given to good housekeeping and salvaging at the source. All non-fat-bearing wastes should be excluded from the retention unit. A detention time of 60 min. for the average hourly flow of fat-bearing wastes is recommended although this will vary with the type of grease involved. The grease interceptor should have underflow inlet and outlet baffles and skimming facilities. Provisions should be made to discharge settled solids from the unit.

A method is presented for testing grease retention unit efficiency. This method consists of collecting samples from turbulent sections of outfalls over a 10–12 hour period in a 55 gal. drum equipped with an overflow draining from the bottom. By regulating the volume and frequency of sampling, various detention times can be established. In this way the actual recoverable material is determined.

ROBERT G. MERMAN

Problems in Paper Mill Waste Disposal. BY H. W. GEHM AND DON E. BLOODGOOD. *Proceedings* of the Second Industrial Waste Conference, pp. 40–45, Purdue University, 1946.

A classification of the materials that may be present in waters discharged from manufacturing establishments is given and a discussion is made of each class as it pertains to the pulp and paper industry.

The loss of usable raw material in this industry is small compared with the amount of unusable solids discharged in the waste water. The largest loss of usable raw material occurs when waste paper is the source of fiber.

The loss of product, that is, cellulose fiber, occurs chiefly during washing and fabrication of the sheet and runs well under 1 per cent in both of these operations.

Residues remaining after the extraction of the product from the raw material and compounds produced in processing by side reactions are manifold and constitute the principal sources of polluting material present in the waste waters of this industry, although major by-product processes remove a portion of the polluting material, residual substances similar to those originally present in the waste remain.

The sulfate and soda pulping processes are economically feasible because most of the chemicals employed are recovered. However, excessive loss of chemicals may occur during irregularities in the recovery system and in starting or stopping the process or during clean-ups.

Factors to be considered in solving individual problems include: (1) flows and characteristics of the receiving waters; (2) uses to which receiving waters are put; (3) degree and character of other pollution; (4) processes employed in mill; (5) physical layout of mill including sewering; (6) type and variations in raw material employed; (7) size of mill in respect to production; (8) geographical location; (9) operation and personnel; (10) type and condition of equipment; (11) recovery systems; and (12) by-product manufacture.

ROBERT G. MERMAN

New Developments in the Disposal and Utilization of Waste Pickling Liquors. BY RICHARD D. HOAK. *Proceedings* of the Second Industrial Waste Conference, pp. 46–53, Purdue University, 1946.

Seven Mellon Institute research projects on the disposal of waste sulfate pickling liquor are briefly outlined. With one exception, these projects have been limited to laboratory investigation only. They are as follows:

(1) The use of iron sulfate in portland cement in place of gypsum. Cements in which iron sulfate was substituted for gypsum on the basis of sulfate content were prepared having tensile and compressive strengths which compared favorably with a good grade of portland cement. Cements containing iron sulfate have a cream to light brown color as compared with the light gray of ordinary cements.

(2) The precipitation of ferrous sulfate from the pickling liquor with acetone and the recovery of sulfuric acid and acetone by distillation. After six pickling and recovery cycles, there was no apparent accumulation of impurities in the recovered acid.

(3) Production of ferric chloride and sodium sulfate by means of differential crystallization. Sodium chloride and chlorine are used in this process.

(4) The concentration of low-grade manganese ore using waste pickle liquor as a reducing agent. A manganese oxide containing over 60 per cent manganese is produced.

(5) The use of limestone in treating waste pickle liquor. The use of high calcium limestone (containing less than 2 per cent magnesium carbonate) to neutralize the free acid precipitate part of the iron, substantially reduces the amount of lime necessary to complete the treatment. This method is presently in use in a steel plant and attractive savings have resulted.

(6) The use of waste pickle liquor to recover magnesia from dolomitic lime. This process produces a high purity calcium sulfate and a 91–94 per cent magnesia.

(7) The production of magnetic iron oxide. It was found during neutralization procedures that when approximately two-thirds of the ferrous iron is oxidized to the ferric state and the solution is treated with an alkaline agent, the iron is completely precipitated as magnetic oxide. This material appears to have some promise as a pigment and pure ammonium or sodium sulfate, depending on the alkali used, can be recovered.

ROBERT G. MERMAN

Vegetable Wastes—Their Availability and Utilization. BY R. HENRY MORRIS, III. *Proceedings* of the Second Industrial Waste Conference, pp. 54–69, Purdue University, 1946.

The Eastern Regional Research Laboratory of the United States Department of Agriculture has undertaken an investigation of the wastes incident to the production and processing of vegetables in order to determine commercially feasible methods for utilizing their valuable constituents to the fullest extent. Wastes from the following vegetables were given considerable study as their use in poultry and animal feed appeared most promising from the standpoint of abundance, occurrence in large concentrations and nutritional value: Beets, broccoli, cabbage, carrots, cauliflower, kale, lima beans, peas, rutabagas, turnips, and spinach.

Analyses for carotene, riboflavin and in some cases protein, crude fiber and fat were made to evaluate the nutritional value. In a few cases vitamins E and K, chlorophyll and xanthophyll were determined. The leaves were found to be the richest part of the plants in valuable nutritional constituents. The chemical analysis of leaf meals on the bone-dry basis showed the following variations: Carotene from 111 p.p.m. for carrot tops (early) to 595 p.p.m. for broccoli. Riboflavin from 64 p.p.m. for carrot tops (early) to 29.1 p.p.m. for spinach. Protein from 10.4 per cent in carrot tops (early) to 35.3 per cent for broccoli.

Process and equipment specifications, based on E. R. R. L. pilot plant studies, are given and estimations of expected yields, costs and nutritional values are made.

ROBERT G. MERMAN

The Composition of Metal-Plating Wastes. BY WILLIAM J. EHLEN. *Proceedings* of the Second Industrial Waste Conference, pp. 70–81, Purdue University, 1946.

Metal plating is defined as an "electrochemical process by which an article fabricated of some common base metal can be coated with another tightly adherent metal that possesses certain desirable physical or chemical characteristics."

A typical plating process shows any or all of the following operations:

"(1) The fabricated article is cleansed of oil or grease by soaking in organic solvents, or in vapor degreasing units.

"(2) If necessary, rust or scale is removed by pickling in a suitable acid, such as muriatic or sulfuric.

"(3) The acid film is removed by rinsing in water.

"(4) The article is cleaned electrolytically in a hot alkaline cleaning solution.

"(5) Next come water rinsing and dipping in weak acid to remove cleaner residue, followed by further rinsing.

"(6) Finally come the plating operation and final rinses."

The chemistry of the alkaline type zinc plating bath is discussed in detail, showing that the waste products discharged to the sewer through the rinses are: $Na_2Zn(CN)_2$, $Na_2Zn(CN)_4$, NaOH, NaCN, Na_2CO_3, Na_2ZnO_2, Na^+, Zn^{++}, $Zn(CN)_4^{--}$, ZnO_2^{--}, CN^-.

In like manner, cadmium plating, copper, chromium and nickel plating are described, as is anodizing and bright dipping.

"The regular source of plating wastes is the overflowing rinses which remove the film of solution clinging to the articles being processed as they move from one bath to another in the plating sequence. These wastes are, therefore, always diluted except for the infrequent occasions when an entire bath is discarded by dumping."

A typical analysis of a plating waste is given from a plant discharging 50,000 gal. of waste but it is also mentioned that the analyses vary from plant to plant and too few analyses of these wastes have been made. The cyanide content may range from 1 to 100 p.p.m. and chromium from 2 to 500 p.p.m.

The author has appended the typical composition of all plating solutions.

H. GLADYS SWOPE

Brewery Waste Utilization. By B. H. NISSEN. *Proceedings* of the Second Industrial Waste Conference, pp. 82–89, Purdue University, 1946.

The various steps of malting and brewing are outlined and the wastes resulting in each step are listed.

The brewing of beer involves malting and brewing. The grain is soaked in large tanks with copious quantities of water. The grain particles which float are run through screens and the water goes to the sewer. The grain then goes to malting tanks for germination and becomes what is known as green malt. No waste liquids result from this process.

In the brewing of beer, malt and rice or corn grits are used. These are ground and mixed with 4 to 5 times their volume of water. This mash is transferred to other large cylindrical tanks with false bottoms. The extracted spent grains are left behind and this is now dried by passing through presses. The waste liquid contains .75 to 2.5 per cent solids. There are no further wastes until the operation following fermentation, such as carborating, cooling and filtering, "when certain small amounts of rests result which are normally flushed off to the sewers with large quantities of water."

There are alkaline wastes from bottle washing.

The author maintains that the few waste materials resulting from the brewing of beer which are not disposed of as salable by-products, are in the first place very dilute and secondly dispersed generally in well aerated water.

ROBERT G. MERMAN

Industrial and Domestic Wastes in Relation to the Aquatic Life of Indiana Streams. By WILLIAM E. RICKER. *Proceedings* of the Second Industrial Waste Conference, pp. 90–96, Purdue University, 1946.

Aquatic organisms are classified as plankton, bottom organisms, swimming animals and useful stream animals.

Plankton are animals or plants which float free in the water or move about in it only slowly or weakly.

Bottom organisms as a group are called benthos. Benthic plants and animals vary from microscopic to relatively large microscopic forms the same as plankton.

Swimming animals called nekton include nothing but fish, for practical purposes.

Useful stream animals include fish and mussel. Fifty-six species of fish are directly useful to man in this state. A conservative estimate of the potential annual productivity of useful stream fish is 100 lbs. per acre. This capacity is probably not utilized. Mussel are used to make pearl buttons. The food value of mussel and crayfish or crawdads is not utilized commercially.

Fish depend on plants as their primary food supply. They may eat either plankton, benthos or other fish. A food cycle is established by the use of smaller plants and animals as a source of food by larger forms.

Wastes, having deleterious effects, are divided into two general classes: (*a*) Those which can, in sufficient concentration, kill water animals directly and (*b*) those which, by reason of their organic content, can reduce the oxygen in the water to a point where many organisms cannot survive. Illustrations of (*a*) may include hot water, oil well brine and cyanide wastes. Toxic wastes may not kill all the life of a stream. In general the larger the organism and the more complex its or-

ganization of life the less is its tolerance to extreme conditions. Thus rich crops of potential fish food may exist but no fish can be found that is able to utilize them under their conditions of occurrence. Oxygen consuming wastes may cause spectacular mortalities at intervals with subsequent repopulation of the stream on the disappearance of adverse conditions. Downstream from the direct adverse effects of these wastes there are generally favorable conditions for the growth of fish food organisms and fish. The advantage to fish production has not been evaluated. However, fish caught in grossly polluted waters generally smell and taste like the water. Nevertheless, the author recommends the experimental investigation of the use of fish ponds for domestic sewage disposal at some Indiana plant.

ROY F. WESTON

Industrial Wastes of the Ohio River Basin. BY M. LEBOSQUET, JR., AND S. W. WEIBEL. *Proceedings* of the Second Industrial Waste Conference, pp. 97–107, Purdue University, 1946.

The authors give a brief summary of the status of current industrial wastes pollution-corrective measures in the Ohio River Basin. The summary was based on reports on 1,800 different industrial establishments.

At the time of the survey (1939 to 1941) industrial wastes with an oxygen demand had a population equivalent of 10,000,000. Of these about 12 per cent was being treated with municipal sewage. At the same time 34 per cent of all domestic sewage in the valley was receiving treatment. In the U. S. as a whole 60 per cent of the sewage is treated.

TABLE I.—Summary Showing Industrial Wastes Not Discharging to Municipal Treatment Plants, Suggested Industrial Waste Discharges to Municipal Treatment Plants, and Total of Entire Industrial Load in the Ohio River Basin

Industry[1]	Number of Plants	Industrial Waste Disposal		At Least Minor Corrective Measures Taken	Estimated Sewered Population Equivalent (B.O.D.)	Suggested to Municipal Treatment	
		Municipal Sewers	Private Outlets			Number of Plants	Population Equivalent (B.O.D.)
Brewing	38	35	3	27	264,300	37	263,800
Distilling	67	14	53	53	1,009,700	20	624,600
Canning	218	52	166	160	758,900	64	310,300
Meat	173	76	97	115	385,700	123	323,900
Milk	253	130	123	107	85,100	167	74,700
Tanning	32	5	27	13	269,600	13	55,400
Paper	59	12	47	46	1,659,200	5	31,500
Oil refining	47	4	43	44	116,500	2	15,100
By-product coke	23	2	21	17	745,200	2	24,300
Steel	174	15	159	71	[2]	12	0
Chemical	65	10	55	36	1,880,400	8	138,000
Textile	122	57	65	10	335,100	84	216,900
Miscellaneous	333	104	229	109	160,300	89	132,500
Total	1,604	516	1,088	808	7,670,000	626	2,111,000
Industrial wastes to Cincinnati sewers[3]		...	..		1,108,400	...	1,108,400
Wastes discharged to municipal treatment		...	...		1,195,900	...	.....
Totals for the Basin		...	...		9,974,300	626	3,319,400

[1] Industries occurring only once in an Ohio River tributary basin are included under "Miscellaneous" in the tributary basin summaries given in House Doc. 266, 78th Congress, 1st session, but are under their proper classification in this table.

[2] 336,000 pounds free acid discharged daily in waste pickle liquor.

[3] Industries not surveyed individually. Population equivalent based on comprehensive sewer gaging and sampling program of city.

It was estimated that 45 per cent of the organic industrial wastes could be treated with municipal sewage. A summary of plants not discharging to municipal treatment plants is shown in their Table I attached.

Acid mine drainage is one of the most serious industrial wastes in the valley. It is estimated that total charges for mine sealing based on normal peacetime mining operations would be about six mills per ton of coal mined.

The writers pointed out that the U. S. Public Health Service cooperates with the Corps of Engineers, U. S. Army, on studies for the construction of multipurpose reservoirs which may be used to increase minimum flows in streams thereby affording savings in pollution abatement costs.

Brief summaries of pollution abatement practices are given for brewery, distillery, cannery, meat, milk, tannery, paper, oil refining, by-product coke and steel mill plants.

A summary of estimated costs of industrial waste pollution abatement facilities in the Ohio River Basin is given in Table II.

TABLE II.—Summary Showing Costs of Municipal Sewage Treatment Plants, Intercepting Sewers, and Industrial-Waste Treatment in the Ohio River Basin

Treatment plants for municipal sewage only	$ 61,900,000
Additional capacity for industrial wastes	13,100,000
Total cost of municipal plants	$ 75,000,000
Intercepting sewers to municipal plants	85,330,000
Total municipal costs	$160,330,000
Cost of treating or otherwise correcting industrial wastes	13,600,000*
Cost of mine-sealing program	16,000,000
	$189,930,000

Note: Estimates based on average cost experience from 1928 to 1940.

* Does not include items difficult if not impossible to estimate.

ROY F. WESTON

Industrial Waste Treatment in Germany. BY J. J. GILBERT. *Proceedings* of the Second Industrial Waste Conference, pp. 108–113, Purdue University, 1946.

The author visited Germany in 1945. He reported the status of industrial-waste treatment from 1938–1945 to be as follows:

1. About 70 plants were remodeled or built during this period. They were chiefly the following types: (*a*) Phenol-waste treatment and recovery, (*b*) pickling liquor (iron, copper, chromium), (*c*) acid neutralization and (*d*) coke wash-water clarification.

2. Recovery of valuable constituents in the waste liquors was stressed.

3. In general, the plants built used the same type of units as are employed in the U. S. for mixing and settling.

4. No new processes or major items of equipment were developed during the war years.

Items of special interest included: (*a*) methods of treating cyanide, chromate, pickling liquor, copper and phenolic wastes, (*b*) equipment for handling coke wash water and (*c*) stage neutralization of acid waste by means of automatic pH valve control. The author briefly described each of the above items and showed slides.

Those interested in details relative to these items are referred to a report prepared by the War Utilities Subcommittee T. I. I. C. under the direction of the "Field Information Agency, Technical." This report is published by the Commerce Department, Washington, D. C.

ROY F. WESTON

Economies in Industrial-Waste Treatment Plant Design. BY B. A. POOLE. *Proceedings* of the Second Industrial Waste Conference, pp. 114–120, Purdue University, 1946.

Effort should be made to reduce the installation cost of industrial waste treatment works. Studies of plant processes, including a thorough survey and analysis of wastes involved; the use of smaller factors of safety; and the use of simpler construction and treatment processes are justifiable and will serve to accomplish this reduction.

ROBERT G. MERMAN

Workshop on Milk Wastes. Presiding: Mr. W. Scott Johnson, Dr. H. A. Trebler, and Mr. J. M. Trimble. *Proceedings* of the Second Industrial Waste Conference, pp. 121–135, Purdue University, 1946.

Mr. Johnson and Dr. Trebler described the development of a task committee on Dairy Waste Disposal under the subcommittee on Sanitary Standards of the Dairy Industry Committee. A general discussion on milk wastes followed.

ROBERT G. MERMAN

Workshop on Wastes from Food Processing. Presiding: V. R. Rupp, Paul DeLeon and Charles W. Templeton. *Proceedings* of the Second Industrial Waste Conference, pp. 136–143.

Mr. Rupp: **Wastes from the Meat Packing Industry.**

The meat packing industry has two distinct types of waste, grease and high protein material, both of which are to a large extent recoverable with profit. The largest source of waste of both of these materials is the rendering operation. Reduction of wastes at the source and the use of properly designed and maintained recovery equipment is recommended.

Mr. DeLeon: **Dehydration of Feeds.**

On the basis of surveys and tests on 20 existing dehydration plants and experience gained in three years' operation of three pilot plant units, a design was prepared for a universal feed dehydrating plant.

Fuel costs are the main source of expense, with labor next. Transportation costs are such that 10 miles is about the maximum haul that can be safely considered. The operation costs can only be kept down by the unit or units at a high load factor. Some of products processed are pea vines, pea pods, citrus refuse, corn waste, corn stalks, carrot tops, turnip tops, liver refuse, brewers grain and many others.

A general discussion followed.

ROBERT G. MERMAN

Workshop on Oil Refinery Waste Recovery, Some Problems of Oil Refinery Waste—Collection and Segregation. By M. J. MORGAN. *Proceedings* of the Second Industrial Waste Conference, pp. 144–146, Purdue University, 1946.

Liquid wastes from an oil refinery can be divided into three general classifications based on type of sewage and degree of treatment. These are (1) sanitary sewage, (2) spent cooling water, and (3) process and storm water. Segregation of these three types of wastes is advisable. Sanitary sewage will interfere with the treatment of refinery industrial wastes and is usually best disposed of in the adjacent municipal sewer. Spent cooling water consists chiefly of large volumes of water that is clean except for occasional small amounts of oil due to temporary leaks in cooling equipment. Gravity separators are adequate to prevent this oil from reaching lakes or streams. Process and storm water are combined in a single system because they have one thing in common, namely oil.

It is usually best to construct new sewerage systems for sanitary sewage and spent cooling water and to use the existing system for process and storm water. Sanitary sewage is, in most cases, most economically handled by a combination of gravity sewers leading to a centrally located pumping station connected to a municipal sewer. The spent cooling water system can often be laid above ground as the sources of this material are usually elevated.

The rule of segregation and treatment at the source should be applied to all wastes to reduce the quantity of sewage and difficulties of treatment at the final disposal plant.

Waste-Disposal Problems in a Refinery. By J. W. RANDOLPH, pp. 147–150.

Some of the wastes likely to be encountered in a medium-sized refinery practicing topping and cracking only are classified as to their origin: still wastes, treating plant wastes, and water treating wastes. In general, the best system of waste utilization in a refinery is that of waste prevention. Treating plant wastes constitute some of the most serious and most difficult disposal problems. In addition to having many obnoxious characteristics in themselves, they often form or promote forma-

tion of stable emulsions in the plant sewerage system. Consequently, it is common practice to keep these wastes segregated as much as possible.

Sulfur Dioxide and Coke Recovery from Acid Sludge. By R. J. Austin, pp. 150–154.

A brief description of the acid sludge coking process is given. This process was developed by the Chemical Construction Company as a means of recovering sulfur dioxide and coke from the sludges produced in acid treating certain petroleum fractions. In general, it involves decomposing the sludge to form coke and gas, the coke going either to storage or to the heating kiln to furnish heat for the decomposer, and the gas (mainly SO_2) going through scrubbers and then being oxidized to SO_3 and absorbed in sulfuric acid.

Robert G. Merman

Workshop on Paper Manufacturing Wastes. Presiding: H. M. Blandin and K. H. Holm. *Proceedings* of the Second Industrial Waste Conference, pp. 155–160, Purdue University, 1946.

A general discussion on the following paper manufacturing wastes: wastes from strawboard mills, wastes from cigarette paper manufacturing, de-inking wastes and waste sulfite liquor.

Robert G. Merman

Workshop on Metal Plating and Steel Mill Wastes. Presiding: D. A. Cotton and A. W. Neel. *Proceedings* of the Second Industrial Waste Conference, pp. 161–176, Purdue University, 1946.

General discussion. A brief description of some of the methods used for the disposal of plating and heat treating wastes was given. The following methods of cyanide disposal were included: Acid treatment, lime-sulfur treatment, hypochlorite treatment, acid plus oxidizing agents, electrolytic oxidation, and milk of lime treatment. The need for research sponsored by the plating industry was recognized.

Robert G. Merman

Workshop on Sewage Disposal and Indusdustrial Wastes. Presiding: W. E. Ross, W. W. Mathews, and R. H. Heider. *Proceedings* of the Second Industrial Waste Conference, pp. 177–182, Purdue University, 1946.

The necessity for measurement of industrial waste flow at sewage treatment plants was pointed out. The importance of close cooperation between the manufacturer and the treatment plant superintendent was also discussed.

Robert G. Merman

Stream Pollution Control in Tennessee. By R. P. Farrell. *J. Amer. Water Wks. Assn.*, **39**, 352–356 (April, 1947).

The progress of stream pollution control in Tennessee parallels very closely the history and development of the Division of Sanitary Engineering in the Tennessee Dept. of Public Health. Studies were made of laws in other states, with a view toward the submission of a proposed law on stream pollution in Tennessee. Several efforts were made to secure legislation, but up until 1945 none was enacted.

Early in 1945 a summary report of work done on stream pollution in the state by the Tennessee Valley Authority, the U. S. Public Health Service and the State Health Dept. was submitted to the legislature. Apparently the information was sufficient to indicate that some means of control was necessary, for the existing law was enacted early in 1945. This act created a Stream Pollution Control Board that adopted the following general regulations that were mailed to all municipalities and industries in the state:

(1) Supervision of new construction by requiring submission of preliminary plans and supporting data.
(2) Supervision over maintenance and operation by requiring the submission of records and reports on operation.
(3) A policy was adopted for investigation of complaints and special investigation of existing or new disposal works. As a guide to the Dept. of Health the Board was to issue standards or other criteria on pollution, in addition to special orders.

(4) Permits to discharge sewage, industrial wastes or other wastes were instructed to be filed under a prescribed procedure.

A Technical Committee was appointed to prepare a "General Criteria for the Definition and Control of Pollution in the Waters of Tennessee," and a preliminary report has already been submitted to various federal agencies for review and comment.

The Board has approved a cooperative program in which the state assumes full responsibility for the study of streams, and municipalities and industries assume responsibility for sewage and wastes, respectively.

Considerable cooperation has been received from the TVA; only consultant service has been received from the U. S. Public Health Service, but further aid is anticipated in the future. The State Dept. of Conservation and the State Planning Commission have assisted with personnel and special studies. In addition, the State of North Carolina has cooperated on interstate problems.

Although progress appears to be a little slow, the establishment of the mechanism for a control program is quite involved. There have been 352 applications received for permission to continue to discharge wastes into Tennessee streams. Only 25 permits have been issued, and others are awaiting the determination of conditions under which permits can be issued. In all, 41 municipalities have begun to study their problems, and 22 of them have received aid for engineering planning from the Federal Works Administration.

At present it is believed that as many projects are under study as would be feasible at one time.

ROBERT P. LOWE

Industrial Use of Streams. BY L. L. HEDGEPETH. *J. Amer. Water Wks. Assn.*, **39**, 532–538 (June, 1947).

This paper approaches the stream pollution problem mainly from the side of industry, and consideration is given to several fears, certain questions and possible means of solving this problem.

There is considerable concern that stream pollution legislation will drive away industrial payrolls, and this is especially true of those industries that emanate wastes for which there is no present practicable treatment method. The author believes that special consideration will have to be given in such cases, but this should not be a valid reason for continued abuse of streams.

It is stated that industry is doing considerable research in stream pollution abatement, but it appears in the record principally as process improvements—process changes to eliminate waste. Regardless of how they are described, any adjustments which reduce the pollutional load are properly classified as abatement measures. However, industry will continue to look at waste disposal from the cost angle, and only appropriate legislation, enforced impartially, will make it possible for industrial plants to meet such requirements and still compete with other plants.

The most profitable place to start correction is in the manufacturing process, and this can best be handled by a chemical engineer. When the plant man has done all that is economical on waste reduction in the manufacturing process, the sanitary engineer must then devise a suitable treatment or diversion of the waste liquors so as to avoid stream abuse. Impressive treatment plants should not be expected—the industrial engineer will endeavor to reduce his problem to its simplest form and then arrange for functional waste disposal units. Specific examples are given in the manufacture of two synthetic insecticides—DDT and the important but as yet lesser known hexachlorocyclohexane, also called benzene hexachloride, 666 or Gammexane.

The difficulty in defining pollution is discussed, and the conclusion is reached that it is not too much B.O.D., sludge, grease, acid or alkali, but too much of anything. The author also gives the viewpoint that the best determination of what constitutes pollution is accomplished by pooling thought in each case and settling details at the local levels.

General waste disposal objectives would be to remove the sludge, scum and grease, destroy or divert objectionable concentrations of toxic agents, reduce discoloration to imperceptibility in the stream, adjust the effluent pH to the normal stream range, and reduce the flowing load B.O.D. to the point where it can be assimilated by the

stream without dropping the dissolved oxygen below acceptable minimums. To accomplish these objectives legislative action is needed to provide a skeleton of strong girders on which appropriate regulation can be constructed to stay. Once the structure is provided, the corrective actions become largely technical, not legal.

ROBERT P. LOWE

New pH Indicators for Determination of Total Alkalinity in Water. By MICHAEL TARAS. *Ind. and Eng. Chem., Anal. Ed.*, **19**, 339–340 (1947).

Two new indicators are suggested for determination of total alkalinity in water. The first, disodium 4,4′-bis(p-dimethylaminophenylazo)-2,2′-stilbenedisulfonate, is especially applicable to colored solutions. The second, disodium 4,4′-bis(o-tolyltriazeno)-2,2′-stilbenedisulfonate, is suggested for colorless solutions. Both cover the methyl orange end-point. The solutions are stable, showing no deterioration in color or properties after a year's preparation. A solution of the first indicator (0.1 per cent) possesses a deep red color. Color changes in the range pH 5.0 to 4.0 vary from pale purple, to a blue-violet. A (0.5 per cent) solution of the second indicator is a brick-red color. At pH 4.7 first changes are apparent, the solution becoming muddy, having a maximum muddiness at pH 4.0. It is suggested that titrations be conducted in a porcelain casserole so as to emphasize the end-points. The indicators are prepared as follows: "Work up into a paste 9.25 grams (0.025 M) of 4,4′-diaminostilbene-2,2′-disulfonic acid, Eastman Kodak T4613, with 50 ml. of distilled water and dissolve by addition of a solution of 2.5 grams of sodium hydroxide pellets in 10 ml. of distilled water. Next stir in 3.45 grams (0.05M) of sodium nitrite, already dissolved in 10 ml. of distilled water, and transfer the resulting solution to a separatory funnel.

"In a 250-ml. beaker mix 25 grams of crushed ice and 25 ml. of concentrated hydrochloric acid, cooling the exterior of the beaker in an ice bath. When the temperature of the acid-ice mixture has fallen to 0°, run in slowly the stilbenenitrite solution, with vigorous stirring. If necessary, add ice from time to time to maintain reaction temperature below 5° C.

"Remove the beaker, still in the ice bath, to a refrigerator and allow the yellow diazonium salt to settle for an hour. Siphon off the supernatant liquid and rapidly add the diazonium slurry to the coupling solution which has been prepared in the meantime.

"The coupling solution consists of 7.3 ml. (0.06M) of dimethylaniline, Eastman Kodak 97, in 25 ml. of glacial acetic acid. Allow the reaction to take place at room temperature for one hour, with continuous stirring.

"Filter the precipitate and dry. Recrystallization is unnecessary. Triturate the dye with the calculated volume of 0.05N sodium hydroxide and dilute sufficiently to form a 0.1 per cent solution.

"In the preparation of disodium of 4,4′-bis(o-tolyltriazeno)-2,2′-stilbenedisulfonate the preceding procedure was adhered to with one exception; the coupling was effected with 6.0 ml. (0.06M) of o-toluidine, Eastman Kodak 253. The indicator was prepared in 0.5 per cent solution."

T. JAFFE

Tetraethylenepentamine as a Colorimetric Reagent for Copper. By THOMAS B. CRUMPLER. *Ind. and Eng. Chem., Anal. Ed.*, **19**, 325 (1947).

Several methods for the colorimetric determination of copper are available at present. Tetraethylenepentamine is suggested as a reagent which gives a color reaction with cupric ion a sensitivity intermediate between ammonia and the recently developed reagents of high sensitivity. All work was done on a spectrophometric and a photoelectric colorimeter. The amine was found to be 3.5 times as sensitive as ammonia. Color development is independent of excess amine. Beer-Lambert law is followed over a concentration range of 0 to 160 p.p.m. copper.

"To prepare 100-ml. portions of colored solution of the copper tetraethylenepentamine complex with cupric ion concentrations of 0 to 200 p.p.m., 10 ml. of 2 per cent aqueous solution of amine should be used. This provides a plentiful excess of amine if the pH of the copper solution is not less than 3.5 to 4.0. Regulation of the pH to this range can be satisfactorily accomplished by dropwise addition of dilute sodium hydroxide solution and testing

with an indicator paper. If too much sodium hydroxide is added and cupric hydroxide precipitates, it is all right to add the amine but the mixture must be allowed to stand several minutes to permit complete solution of the cupric hydroxide. Observations over a period of 48 hours reveal that the color is perfectly stable for at least this time.

"The ions which interfere with this amine are the ones which interfere with ammonia."

T. JAFFE

Biggest Non-Self-Propelled Disposal Barge Launched. *Marine News*, **34**, 46–50 (Aug., 1947).

The launching of the 265-foot waste-disposal barge "Sayreville," on June 20, climaxed 13 years of intensive study of waste disposal methods by the Titanium Division of the National Lead Co.—years in which $10,000,000 was spent on research, experiment and operation of various disposal methods.

Decision to dispose of the liquid wastes at sea was the last resort of the company. The wastes are expected to aggregate 4,000 tons (8.5 per cent H_2SO_4) per day by early 1948. The decision was reached after consultation with experts in the fields on marine life and oceanography, and the final program was prepared by the Fish and Wildlife Service in cooperation with the Atlantic States Marine Fisheries Commission and the National Lead Co.

The "Sayreville," with a length of 265 ft., beam 43 ft., and depth of 20.75 ft., is the largest acid disposal barge ever built. The barge will carry the wastes to a point 13 miles southeast of Scotland Lightship, 10 miles off the New Jersey coast. The waste will be unloaded in a 2-mile square area located over a deep and rocky section of the old Hudson River Gorge, an ocean-bottom canyon extending out to sea. The area will be 5 miles from the "Mud Hole" fishing grounds, from which a residual current flows away toward the canyon at a rate of about 5 miles per day. The ocean depth is more than 150 ft. at the disposal site.

The waste will be discharged through two 12-in. pipes located at the keel and at the extreme after end of the barge. The waste will discharge at a rate of 2,500 g.p.m. and the barge will move ahead at 600 ft./min. It has been estimated that the rapid dispersal of the waste will result in no measurable alteration of the number, location or habits of the fish in the area, nor in any measurable diminution in the volume of plankton. There will be no cumulative effect from the waste, no discharge in any fishing ground (the assigned area is not used by commercial fishermen because of danger of damage to nets), and no effect on New Jersey beaches. A permit to operate the barge has been obtained from the Port of New York. Nineteen trips every two weeks will be required to dispose of the maximum waste volume from the plant.

RICHARD D. HOAK

Refinery Waste Disposal—XVIII. Secondary Section of Oil-Water Separator Effects Final Clean-up of Refinery Waste. BY W. B. HART. *Petroleum Processing*, **2**, 513–517 (July, 1947).

The primary section of an oil-water separator effects a rough removal of oil and of most of the settleable solids, while the secondary section provides a final clean-up of the waste water prior to discharge. Although every effort is made to maintain the proper type of flow in the primary section, the sedimentation process creates a certain amount of turbulence. This requires a redistribution of the flow to the second section; it is accomplished by a distribution system similar to that used in the first section.

The flow-line of the second section must be lower than that of the first, but not so low as to cause unnecessary loss of head, because in many localities little head-loss is permissible due to the nature of the terrain. Generally, the head on the secondary section distribution weir should be a distance below the crest of the primary section outfall weir equal to the head on the outfall weir at design capacity flow. Normally, the flow depth of the second section will be 94 per cent of the first section.

The film rupture chamber of the secondary section may be used for film rupture or for agglomeration, depending on the type of waste water. In some cases, small masses of suspended matter may pass over from the primary section; these may be

broken up by filling the chamber with coke or by using burlap as a coarse filter medium. In any event, if the waste that passes into the secondary section consists mainly of clean oil and water, the efficiency of separation will be greatly increased.

The film rupture chamber may also be used to agglomerate small oil globules to form large ones which separate more readily from the water. An outstanding new material for this purpose is coarse, coated glass wool. The coating provides preferential wetting, causing the oil to agglomerate. Obviously a very dirty waste cannot be treated in this fashion because the coating would soon become ineffective, and the wool would clog with solid matter.

The secondary section is the same width as the primary, but slightly more shallow. It is longer, to compensate for the lack of perfect distribution. In discussing the theory of laminar flow it was shown that the maximum velocity must not exceed the calculated average velocity by more than 35–50 per cent. The length of the secondary basin, in consequence, has been set at 140 per cent of the primary section.

The oil retention baffle of the secondary section has been designed to retain the greatest amount of oil possible; this is a matter of considerable nicety. All those forces that must be related and controlled in separator design are small in absolute value, but their effects may be relatively great. By careful evaluation it is possible to turn these forces to useful purposes.

When a filament of water, moving along the longitudinal axis of the sedimentation in a horizontal plane, contacts a vertical interrupting surface such as an oil retention baffle, its energy is dissipated in a pattern on the vertical surface through 360° as eddy currents. The upper half of the symmetrical pattern moves upward, and tends to sweep oil globules to the flowline. But the lower half tends to move the globules downward into the current moving under the baffle to the discharge weir. This condition is overcome by designing a curved retention baffle so that the water filament path will not be normal to the baffle at any point. This curvature takes the form of a quadrant of an ellipse, and the article gives the mathematics of the design.

The question of whether to install cleaning equipment in the secondary section has often been raised, and the answer will depend on the character of the waste water entering it. If the waste actually is in good condition there will be no need for frequent cleaning. Bottom sediment can be removed at intervals by pumping sludge from a sump ahead of the final weir. Best practice is to install a sludge reservoir and pump, and the bearings and guides for a flight scraper, but to defer the addition of the flights until experience shows that they are necessary.

The article includes a number of sketches of design features.

RICHARD D. HOAK

Interstate Cooperation in Stream Pollution Control. By L. F. WARRICK. Wisconsin State Board of Health Quarterly *Bulletin,* **8,** 104 (October–December, 1946).

This paper describes the establishment of the regional sanitation plan in several mid-western states, and outlines some of the activities and results accomplished under the plan.

In 1925 the legislatures of Wisconsin and Minnesota enacted measures which provided a framework for regional action against pollution of the Mississippi. Later in the same year an inter-state group was formed.

During 1925–26 these two states cooperated in making a thorough study of Mississippi River pollution between the Twin Cities and LaCrosse.

In 1935 the health commissioners of Illinois, Iowa, Minnesota, Missouri, and Wisconsin adopted the Upper Mississippi River Drainage Basin Sanitation Agreement. This agreement provided "for joint action in dealing with common problems, particularly those of a sanitary engineering nature."

In July, 1941, Indiana became the sixth signatory to the Upper Mississippi River Drainage Basin Sanitation Agreement.

In 1941 this group made an intensive study of high-rate filtration plants, and the results of this study are well known to those in the sanitary engineering field.

In 1941–42 study of malaria incidence in the region was made and results have been made available in a pamphlet, "Report on Malaria Survey Along the Upper Mississippi River."

By the formation of such cooperative groups much more can be done by pooling of resources than can be accomplished by a single state.

GERARD A. ROHLICH

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